SIMULATION EVALUATION OF THE COMBAT VALUE OF A STANDOFF PRECISION AIRDROP CAPABILITY

THESIS

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14. ABSTRACT
This project is a simulation evaluation of the developmental standoff precision airdrop (SOPAD) capability. SOPAD is a new technology under consideration to deliver supplies to forward-deployed units using either a semi-rigid wing or a guided parafoil. These delivery systems allow airdrop of supplies from altitudes of 25,000 feet and distances 25 miles from the delivery point. Using global positioning system guidance, on board navigational computers, and automatic steering mechanisms, the delivery system flies to the target following a designated flight plan. The concept includes delivering supplies to remote and potentially hostile areas without endangering the supply aircraft. In addition, supplies can be delivered to multiple locations from a single aircraft. The Air Force's THUNDER model was used to simulate the SOPAD capability and observe the impact in the simulated combat environment. The scenario places a light infantry brigade in a position where supply by ground is prohibited due to terrain limitations and it must hold its position until relief forces are available. The unit must fight for a one-week period being resupplied only through airdrop. The results of the simulation are measured through aircraft attrition, unit strength, forward line of troops movement, and the supplies delivered to the unit.

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Abstract

This project is a simulation evaluation of the developmental standoff precision airdrop (SOPAD) capability. SOPAD is a new technology under consideration to deliver supplies to forward-deployed units using either a semi-rigid wing or a guided parafoil. These delivery systems allow airdrop of supplies from altitudes of 25,000 feet and distances 25 miles from the delivery point. Using global positioning system guidance, on board navigational computers, and automatic steering mechanisms, the delivery system flies to the target following a designated flight plan. The concept includes delivering supplies to remote and potentially hostile areas without endangering the supply aircraft. In addition, supplies can be delivered to multiple locations from a single aircraft. The Air Force's THUNDER model was used to simulate the SOPAD capability and observe the impact in the simulated combat environment. The scenario places a light infantry brigade in a position where supply by ground is prohibited due to terrain limitations and it must hold its position until relief forces are available. The unit must fight for a one-week period being resupplied only through airdrop. The results of the simulation are measured through aircraft attrition, unit strength, forward line of troops movement, and the supplies delivered to the unit.

SIMULATION EVALUATION OF THE COMBAT VALUE OF A STANDOFF PRECISION AIRDROP CAPABILITY

1 Introduction

1.1 Overview

Developing and adapting new technology to the continually changing challenges of the modern battlefield pose an on-going struggle for military leaders. As Brigadier General William "Billy" Mitchell said, "In the development of air power, one has to look ahead and not backward and figure out what is going to happen, not too much of what has happened" [1:20-21]. The modern military deals not only with looking to the future and the impact of new technology, but also how to incorporate that technology between the different services. The growing focus on joint operations compels the development of new technology and new tactics to face the battlefield of the future.

A new technology under consideration is the ability to conduct standoff precision airdrop. Under current tactics, aircraft must fly relatively low, slow patterns over large designated drop zones in order to deliver troops and supplies. These requirements limit the effectiveness of airdrop because the aircraft are vulnerable to enemy defenses and the cargo may be dispersed over a wide area. The goal of standoff precision airdrop (SOPAD) is to allow the delivery aircraft to fly at a higher altitude, at a greater distance from the designated drop zone, and deliver the cargo in a precise manner. This not only keeps the aircraft from potential enemy threats, but also allows supplies to be delivered to multiple locations simultaneously with one pass.

Potential benefits of SOPAD appeal to both the Army and the Air Force. Development of the SOPAD capability interests the Army because it would allow for greater flexibility in the delivery of logistics and could lead to great benefits to the insertion of airborne troops [3]. The Air Force can benefit from this technology through reducing the risk to airborne delivery aircraft and increasing the efficiency of the aircraft being used. In addition to these benefits, there is the need to look to the future and prepare for the battlefield of the 21st Century. Highly mobile and dispersed forces on the modern battlefield will need a means for rapid and timely resupply. SOPAD may be the technology that revolutionizes the battlefield of the future. Additionally, SOPAD can be used in other missions such as special operations, humanitarian relief, and the delivery of leaflets in psychological operations.

1.2 Airdrop

Airdrop is a technique that is used to deliver equipment, supplies, and personnel to locations where there is no landing zone for aircraft or where the ground transportation network is not available. According to the Air Force's draft doctrine document 2-6.1 version 2, "Airdrop is the delivery of personnel and materiel from an aircraft in flight to a drop zone (DZ)" [17:15]. In general, airdrop procedures use parachutes to deliver loads to the ground including heavy equipment, container delivery systems (CDS), and personnel. Airdrop allows commanders to project and sustain combat power into remote areas that could not otherwise be reached by ground or landing aircraft. This delivery method allows rapid insertion of combat forces to numerous objective areas to maximize

the principles of surprise and maneuver. There are several advantages and disadvantages associated with this type of delivery.

The advantages are summarized in five basic points. First, airdrop minimizes aircraft and personnel exposure to threats at the objective area, assuming the alternative is landing the aircraft to off-load supplies. Second, it permits sustainment deliveries to units operating away from airfields and large landing zones. Next, it permits the delivery of combat forces and materiel in minimum space and time. Fourth, it permits the delivery of personnel and materiel in environmental conditions that would prevent land operations. Finally, it eliminates the need for ground support infrastructure and personnel [17:16].

There are also several disadvantages to airdrop operations. One disadvantage is the increased risk of injury to personnel or damage to cargo during the drop. Another disadvantage includes the special training required for riggers, transported personnel, and the aircrews. Next, the amount of cargo is limited due to the additional rigging required for airdropped materiel. Finally, it may decrease aircraft range due to low-level ingress/egress and formation tactics required to conduct the operation [17:16].

1.3 Airborne Tactics

The mission of airborne forces is to execute parachute assaults to destroy the enemy and to seize important objectives. Airborne forces have the unique ability to provide a quick response on short notice, and to bypass land and sea obstacles. Airborne forces also capitalize on the element of surprise and provide the ability to mass rapidly on critical targets [2: 1-4]. Typical airborne operations require joint coordination between

the Air Force and Army to achieve the aggressive, rapid seizure of the assault objective. Current Airborne operations doctrine and procedures require that aircraft fly at low altitudes and slow speeds to conduct airborne operations. This practice helps reduce the dispersion of the paratroopers during the landing phase of the operation and increases the survivability of the parachutists that are vulnerable during long, slow descents [2: 4-23]. Unfortunately, this also makes the aircraft and paratroopers very vulnerable to enemy attack while en route to the drop zone. As a result, larger operations require the neutralization or suppression of enemy air defenses. In addition, the formations must fly over designated and well cleared drop zones which can compromise the element of surprise and is very difficult to guarantee. When conducted in hostile territory, the aircraft are very vulnerable to anti-aircraft weapons and shoulder fired surface to air missiles.

Research is underway to develop a new airdrop delivery system to insert airborne forces and supplies to improve the chances for conducting a successful mission. The goal of this new delivery system is to deliver infantry units, their special equipment, and supplies with a high degree of precision even at night or in adverse weather conditions. In addition, the delivery system can be released from higher altitudes and from a greater distance from the designated drop zone. This ability will enhance the element of surprise for the assault force and allow cargo aircraft to avoid enemy threats. The delivery systems will be controllable using the global positioning system (GPS) or some other guidance system to allow the troops or supplies to be delivered to a precise location. If successful, this new technology will deliver the combat troops in a more precise and safe manner while keeping the delivery aircraft at a safer distance and with a less predictable

flight path. This technology could also be used for the insertion of troops and supplies in hostile territory, restricted terrain, or isolated locations.

Standoff precision supply is expected to be the first step in developing the additional technology of delivering troops in a precise manner. The near term goal (within the next five years) is the precise delivery of supplies and equipment to within 100 meters of a designated point [3]. Additionally, the drop can be made from up to 50 miles away and at an altitude of 25,000 to 50,000 feet. Development of this capability will continue with the goal of improving accuracy and reliability. The final phase of this project is the ability to deliver intact infantry units with their equipment. Ultimately, troops and supplies can be delivered with precision and stealth. This ability will enhance the element of surprise and the ability of the ground troops to achieve their mission objective. Standoff delivery helps the aircraft avoid enemy air defenses, simplifies the requirement for suppression of enemy air defenses, and potentially reduces the aircraft turn-around time [3].

1.4 Standoff Precision Airdrop

Investigation into a new airdrop delivery system that will allow precise delivery of troops and supplies from greater distances sparks the interest of both the Army and the Air Force. This new technology has been generally referred to as Standoff Precision Airdrop (SOPAD). The name gives insight into the two key advantages and capabilities that are desired. The first, standoff, will allow people and equipment to be dropped from higher altitudes and greater distances from the drop zone. Using steerable canopies, semi-rigid airfoils, or other methods of flight will give a higher glide ratio and allow the

system to essentially fly itself to the drop zone. The second key aspect, precision, is possible through a guidance system using GPS technology or some other navigational aid to ensure delivery to precise locations.

The development of a new airdrop delivery technology has the potential to save aircraft and enhance the performance of our light combat units. In addition, it may open the door for new scenarios to employ airborne, and air assault operations. This technology may have other applications such as the airborne re-supply of forward deployed combat units in a timely and precise manner, or the delivery of humanitarian relief.

The benefits of a precision airdrop system are clear, but the actual effects are difficult to quantify. The goal of this research is not to answer any technical or engineering questions regarding aerodynamics or control capabilities. Rather, it is to examine the operational benefits that may be achieved once this technology is available. This study will model a SOPAD capability to show how new technology is incorporated into a combat model and develop measures to provide insight into the combat effects.

This research will investigate the combat benefits of standoff precision airdrop technology applied to sustaining forward deployed units. The intent is to perform an analysis using combat simulations that will examine a scenario under the current capabilities and contrast the measures of merit with a model that simulates the ability to use standoff precision airdrop. Assumptions will be made about the capabilities of this delivery system to incorporate its capabilities in the combat model, understanding there are several alternative technical solutions available. The leading concept for the delivery of supplies is the guided parafoil airdrop delivery system (GPADS). Capabilities and

analysis of GPADS provide a good starting point for the modeling of this system. Certain measures of effectiveness will be used to evaluate the potential benefits of SOPAD. Potential measures include unit strength, forward line of troops (FLOT) movement, supplies delivered, or loss of aircraft, and will be tied to the overall mission of the simulated units. Once measures to compare the two methods have been defined, the next step is to identify a model that is suitable for this type of supply and sustainment.

A scenario must be used to examine current capabilities and the new standoff precision airdrop. The use of an existing scenario based on current force structure and weapons provides a good starting point and will provide a good choice to aid in the validation process. The object of the simulation is to observe relative differences to the outcome of the battle based on the implementation of SOPAD technology. Once the model is working for current methods, the new standoff precision airdrop capability will be added to make the desired comparisons. Examination of current GPADS technology will help accurately depict the new standoff precision airdrop characteristics including volume and weight capacity, survivability, and vulnerability.

Accurate data is a key ingredient for getting meaningful analysis from the combat simulation. Since a certain capability is going to be assumed for this simulation, the data used to model the airdrop will be somewhat speculative. Sensitivity analysis on areas such as accuracy of the drop and damage to the supplies will be used to gain insight into the benefits of this airdrop and also show the capability required to be combat effective. Measures of effectiveness must be examined to quantify the differences between SOPAD and traditional airdrop tactics. Analysis of standoff precision airdrop will give insight into potential benefits that can be gained from this new technology and provide insight

into areas for further research and development. Several combat models will be examined to determine their ability to provide insight in these areas and their suitability for modeling the effects of enhanced supply using standoff precision airdrop.

1.5 Simulation Overview

The official Department of Defense definition for the term "simulation" is a model that represents activities and interactions over time. A simulation may be fully automated, or it may be interactive or interruptible. Fully automated simulations run without human intervention. Interactive or interruptible simulations allow incorporation of human decision factors into the running of the simulation. A simulation is an operating representation of selected features of real-world or hypothetical events and processes. It is conducted in accordance with known or assumed procedures and data, and with the aid of methods and equipment ranging from the simplest to the most sophisticated [10].

A model may be defined as a representation of some or all of the properties of a device, system, or object. There are three basic classes of models: mathematical, physical, and procedural. A mathematical model is a representation comprised of procedures (algorithms) and mathematical equations. These models consist of a series of mathematical equations or relationships that can be discretely solved. Usually the models employ techniques of numerical approximation to solve complex mathematical functions for which specific values cannot be derived. A physical model is a physical representation of the real world object as it relates to symbolic models in the form of simulators. Physical models consist of objects such as scaled down versions of airfoils

and ship contours for use in wind tunnels and construction projects such as new buildings. The more properties represented by the model, the more complex the model becomes. Fixed resources such as time, money, and computer assets, create a tradeoff between completeness and complexity. A procedural model is an expression of dynamic relationships of a situation expressed by mathematical and logical processes. These models are commonly referred to as simulations.

The theory underlying the design and use of models is to replicate the characteristics of a system. It is particularly valuable when the desired system, or prototype, is large, complex, and dangerous. A model can be built, tested, and modified at a comparatively low cost. If the model is properly designed, the results can be used with a high degree of confidence in predicting the performance of the actual system [19].

1.6 Thesis Outline

This thesis is organized into chapters to show essential elements in examining the combat worth of SOPAD. Chapter 2 reviews current literature relating to SOPAD and emerging technologies in this area. It examines important capabilities needed for the Army of the future and relates this to the need for an improved airdrop capability. It also discusses systems developed for this capability and their associated performance characteristics. Chapter 3 develops the methodology to implement SOPAD into a combat model and examines several models considered for this study. The goal of chapter 3 is to highlight the complexity of modeling a system that affects both ground combat and air power and show the modeling process for implementing this system as accurately as possible. Chapter 4 reports the results obtained from the modeling process and highlights

both the design of experiment and significant measures of merit. Finally, Chapter 5 presents the findings of the study and provides insights into SOPAD and how it impacted the simulated battlefield.

2 Literature Review

2.1 Logistics on the Modern Battlefield

There are several projects initiated by the Army to look ahead to the battlefield of the future. General Gordon Sullivan first began a concept-based, long-term orientation in the Army with the creation of Force XXI [13:15]. Using Force XXI as a foundation, General Dennis Reimer began a program to look further into the future through the Army After Next (AAN) project. AAN started in the spring of 1996 and was designed to assist in the development of a vision for future Army requirements [4:41]. Through wargaming and experimentation, the Army will identify the critical factors necessary for the future of warfare [6:110]. Investigation into the AAN shows the ideas and key tenets for the Army of the future and the capabilities that it will need. The principles that characterize the Army of the future include knowledge, speed, and power [4:41]. Some initial results of the AAN study indicate mobility and speed of maneuver as the most important factors contributing to battlefield success in the future [6:110]. Several recurring themes give insight into the type of technology and capability needed by the military of the future.

The balance between maneuver and firepower continues to challenge the Army of the future. Each of these two aspects are critical on the battlefield, but are naturally opposed to one another. The ability to move quickly means traveling light, and, therefore, sacrificing the equipment and supplies needed to apply firepower. Maneuver aims to disrupt and then destroy the enemy's equilibrium. Consequently, maneuver must be combined with firepower so that the enemy's entire command and control structure can no longer function [14:50]. It is also projected that as precision weapons proliferate

on the battlefield, it is logical to anticipate that the battlefield will spread out even further [14:50]. This additional distance between combat units will dictate a need to get the supplies and logistical support to multiple locations spread over a larger battlefield. This idea is illustrated by General Scales comment, "A highly mobile and sophisticated ground maneuver force capable of operating in small units scattered across the countryside will deny the enemy refuge and source of sustenance" [14:51].

A key for the AAN involves getting people, supplies, and equipment to the right place and at the right time. As the Army Chief of Staff, General Dennis J. Reimer, states, "Throughout history the Army's major strategic challenge has been getting to the fight" [4:43]. Although this comment refers to strategic mobility, the change to smaller, lighter forces with a reduced logistics footprint will make tactical logistics a major factor. In addition to wartime operations, many other contingencies will continue to confront the United States military. Disaster relief, humanitarian assistance, noncombatant evacuation, combat search and rescue, personnel recovery, sanction or embargo enforcement, preemptive strikes and raids, security assistance, counter insurgency or insurgency support, and nation-building are all missions the future military will handle [7:38]. Logistics planning and capability must improve to deal with these various contingencies.

There are many aspects of logistics expected to improve to help on the battlefield of the future. This has led to the description of the Revolution in Military Logistics (RML). Three of the tenets of the RML for the AAN are rapid force projection, distribution-based logistics, and an adequately small logistics footprint [9:46]. Reduction of the logistics footprint and the need for highly mobile and maneuverable forces will require special

logistical support. The reduction of the logistics footprint opens the possibility to resupply units with a smaller cargo package that could be delivered with an airdrop system. The additional need to reach multiple units in diverse locations fits well into the capabilities of the SOPAD system. These tenets all point toward capabilities well suited for SOPAD that will dramatically improve the ability to conduct operations in AAN at an affordable cost [9:46].

Projects such as Force XXI and the AAN are designed to give insight into the capabilities needed on the battlefield of the future. Although no specific technological capabilities relating to SOPAD have been identified, this technology may provide the logistics flexibility and agility needed for the maneuver and firepower expected in the future. In addition to providing this much needed logistical support to the Army, the protection of Air Force assets will also be critical in hostile environments. Some type of SOPAD system provides a way to deliver the needed supplies to multiple isolated locations and also reduces the threat to the delivery aircraft.

2.2 Guided Parafoil Airdrop Delivery System (GPADS)

There are several conceptual designs under consideration to implement the SOPAD capability. The prominent concepts include a semi-rigid deployable wing and a guided parafoil. Among the designs under consideration to provide a standoff precision capability, GPADS is the most developed and mature system. GPADS relies on advanced sensors, including a global positioning system (GPS) receiver, to feed flight-critical information to an onboard computer [8:83]. The onboard guidance system responds to changing environmental conditions and mission updates to manipulate a set

of actuators that maneuver the parafoil [8:83]. The GPADS development has progressed to the point of actual airdrop testing to prove the conceptual design. Development continues to refine the system and expand capability to larger payloads.

The characteristics of GPADS will be used as a base line for modeling the SOPAD capability. Design characteristics such as size, speed, payload capacity, and vulnerability are available to give a more accurate system to model. There are several versions of GPADS based on size and the payload that each can carry. These versions include the GPADS heavy, medium, light, and extra-light. The GPADS medium uses a 3,600 square foot canopy. The GPADS heavy uses a 7,350 square foot canopy to deliver payloads ranging from 10,000 to 42,000 pounds [9:47]. The concept proved effective at an Army advanced technology demonstration in 1996 when world records were set for the largest parafoil ever deployed (7,350 square feet) and the most weight recovered with a parafoil (36,000 pounds) [9:47].

GPADS uses mission planning software and a laptop computer to load the flight path into the navigation and control unit. The GPADS-light guidance unit consists of a global positioning system receiver, air speed indicator, compass, barometric altimeter, laser altimeter, rate gyros, servos, and batteries to direct the GPADS through its designated route and onto the target [8:84]. A series of way points designate the flight path that GPADS will use to reach the intended target. These way points can be programmed so that the flight path avoids hostile threats en route to the target. One of the leading manufacturers of the large parafoils used by GPADS is Pioneer Aerospace. According to Pioneer's executive vice president, Roger F. Allen, a typical GPADS-light should endure hundreds if not thousands of drops [8:83]. This may pose an overly

optimistic perspective, but the system should provide some reusable characteristics. Figure 1 illustrates the components of the GPADS system and shows the concept of how the guided parafoil delivers its cargo safely to a precise location.

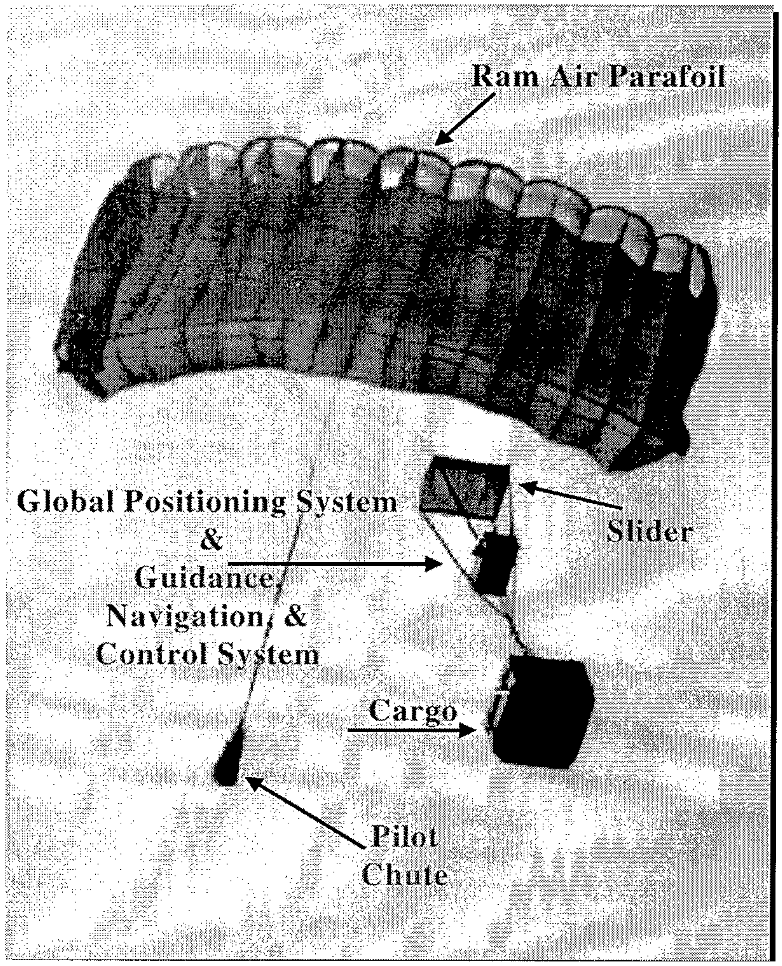

Figure 1. GPADS Components

The availability of different GPADS sizes gives it a wide range of payload options and applications. GPADS increases potential mission applications by offering particular performance characteristics appropriate to the size and the scenario. As the GPADS

technology continues to develop, the ultimate goal is to replace existing airdrop tactics and equipment. Army officials estimate that an airborne division would require 450 GPADS that could bear 1,200 pound loads and a mix of 425 GPADS medium and heavy systems [16:57].

2.3 GPADS Threat Assessment

One challenge associated with developing a new system for military use is determining the performance of the system in a hostile combat environment. In addition to analyzing the performance of the system against current systems, it is also important to consider future enemy capabilities. Since GPADS is being considered as an airdrop technique for the future, this analysis becomes very important. It is important for acquisition and procurement decisions, but also to help model the system as accurately as possible within a combat simulation.

Research Analysis and Maintenance, Incorporated completed a threat assessment on GPADS in March 1995. Experienced threat analysts developed the report based on the most current open-source intelligence available [18]. The intelligence projections and assessments represent the coordinated position of experts in regional threat climate, technical equipment capabilities, and threat forecasting. Estimated probabilities of detection, engagement, and damage are based on the findings of this study.

A threat assessment offers several important elements critical to modeling GPADS. Detection is the first characteristic of the system that must be accurately modeled. In order for the enemy to engage the GPADS, they must first detect it visually or by radar. Weather and other obscurant conditions factor heavily into detection of this system.

Visual detection will also depend on the enemy force deployment, terrain, weather conditions, lighting, observation enhancement equipment, and training [18]. These factors form the basis for the assessed probabilities of detection in Table 1. Devices considered in determining the probability of night observation include infrared, image intensifying systems such as the Russian KAZAN/GAIGYSH series, French SOPELEM-SOFRETEC OB-44, Israeli ELBIT and ELOP series, and Yugoslavian SDPR series [18]. This assessment also assumes adequate operator proficiency, which means that training deficiencies would reduce the detection probabilities accordingly.

Table 1. GPADS Detection Probabilities [18]

System	Daylight/ Clear Skies/ No Obscurants	Daylight/ Inclement Weather/ Smoke and Haze	Night
Unaided eye	.90	.50	.15
Night Observation Devices	NA	NA	.80
Airborne Platforms	.15	.10	.10
Low-Altitude Air Defense Radars	.95	.90	.95
Artillery Fire Direction/ Counter-Battery Radars	.75	.70	.75

The next element needed to engage the GPADS focuses on the command and control structure necessary to identify it as a target to a weapon system that can engage it.

This requires a command, control, and communication (C^3) network that will vary greatly depending on enemy capability. Medium-technology and low-technology environments have been defined to help determine the probability that targeting data will be passed to weapon systems. Medium-technology threats include countries such as China, North Korea, and Iraq. Low-technology threats include countries such as Sudan, Nicaragua, and Gambia. The enemy C^3 system will also be susceptible to electronic countermeasures. In order to evaluate this possibility, environments are considered with and without ECM. Assessments of the probability that acquisition and targeting data will be communicated to an appropriate weapon system in a timely manner are detailed in Table 2 for both of these environments.

Table 2. Probability of Communicating Target to Weapon System [18]

Threat	ECM Environment	Non-ECM Environment
Medium-Technology	.40	.65
Low-Technology	.15	.40

Once the GPADS is detected and targeted, the next consideration becomes the weapon systems likely to engage it. Ground-based air defense systems represent the most capable threats to the GPADS [18]. Four different types of air defense assets are considered first for the probability of engaging the GPADS, and second for the probability that the GPADS will be damaged. The weapons considered include antiaircraft artillery (AAA), manportable air defense systems (MANPADS), tactical

surface-to-air-missiles (SAM), and strategic SAMs. The probabilities for each of these weapon systems is detailed in Table 3.

Table 3. Air Defense Threat Probability of Engagement and Damage [18]

Threat	Probability of engagement: (P_e)	Probability of detection: (P_d)
AAA	.90	.90
MANPADS	.70	.95
Tactical SAMs	.25	.98
Strategic SAMs	.05	.98

In addition to air defense systems, direct fire systems also pose a threat to the GPADS. These systems include machine guns, tank guns, antitank guided missiles (ATGM), or small arms. Each of these systems are capable of engaging the slow-moving, non-evasive GPADS target. Assessment for the probability of engagement and damage is presented in Table 4.

Table 4. Direct Fire Threat Probability of Engagement and Damage [18]

Threat	Probability of Engagement: (P_e)	Probability of Damage: (P_d)
Machine Guns	.95	.85
Tank Guns	.50	.80
ATGMs	.50	.90
Small Arms	.95	.20

Review of this threat assessment indicates that although GPADS presents a slow-moving and non-maneuvering target it poses several factors that increase its survivability. The environment in which the GPADS is employed plays a large factor in its detection and engagement. Factors such as good intelligence and scattered enemy deployments will allow the GPADS to fly through gaps in enemy defenses. Additionally, the GPADS flies a limited amount of time and, depending on the location of the DZ, will only fly a small portion of its mission over hostile threats. The economic value may also deter the enemy from engaging the GPADS. Depending on the situation, the expenditure of a surface-to-air missile may not be warranted. Limiting use to night missions or during inclement weather will further enhance GPADS [18]. Additional tactics, such as the deployment of decoys, may also evolve as GPADS becomes the standard for airdrop missions.

3 Methodology

3.1 Introduction

Modeling and simulation provides a tool to gain insight into the performance of a system without the cost of actually seeing the system operating. This is a valuable tool when testing is expensive and potentially dangerous. Combat simulation is particularly important because it is not normally possible to observe a developmental system in a true combat environment. The nature and complexity of combat make it difficult to model, but at least simulation results can indicate the impact of a new system.

Use of simulation can give insight into the potential combat value of SOPAD capability. There are numerous combat models available, each having different strengths and weaknesses. Modeling SOPAD provides an interesting challenge because it is a new capability and does not have an inherent way of being modeled in current combat models. As a result, the effect of SOPAD must be carefully considered and reflected in the modeling process. In addition, SOPAD requires elements from both air and ground combat. Bringing these two elements together poses additional challenges. There are many combat models used throughout the different branches of service. The challenge is evaluating these combat models and determining the most appropriate one to use.

3.2 Models Examined

Three different combat models were examined for their potential to provide insight into modeling SOPAD. The three models that were examined in depth were the Army's Modular Semi-Automated Forces (ModSAF), and Janus models and the Air Force's

THUNDER model. Janus is one of the Army's standard combat models for high-resolution training and analysis, but it has some limitations. There is no inherent way to model airborne delivery within this model, so a method to accurately replicate the *effects* will be critical for successful comparison. Modular Semi-Automated Forces (ModSAF) is an entity level, high-resolution combat model that was also considered for this simulation application.

The Air Force also has a set of models that are commonly used and accepted to observe the effects of airpower. THUNDER is a campaign level model that simulates many combat effects including logistics and resupply. This provides another option for a model providing insight into the application of standoff precision airdrop technology. Although THUNDER is a campaign level model, it provides adequately high resolution to observe the effects from this airdrop delivery system.

3.2.1 Modular Semi-Automated Forces

ModSAF is a set of software modules and applications that construct Computer Generated Forces (CGF) within a Distributed Interactive Simulation (DIS) environment. These forces create a virtual battlefield environment used for realistic training, test, and evaluation [24:1]. ModSAF provides the capability to create and control entities within a simulated battlefield to replicate the outward behavior of simulated units and their component vehicles and weapons systems to a level of realism sufficient for training and combat development [23]. The entities can move, fire, sense, communicate, and react without operator intervention. In addition, CGF entities can interact with each other and manned simulators over a network supported by DIS [23]. These entities, which include

ground and air vehicles, dismounted infantry (DI), missiles, and dynamic structures, can interact with each other and with manned individual entity simulators to support training, combat development experiments, and test or evaluation studies.

The purpose of ModSAF is to replicate the outward behavior of simulated units and their component vehicles and weapons systems to a level of realism sufficient for training and combat development. ModSAF creates a large number of entities on the virtual battlefield, including fixed and rotary wing aircraft, ground vehicles, dismounted infantry, and additional special models such as howitzers, mortars, minefields, and environmental effects [23]. ModSAF components interface using a set of databases. The different databases contain information about the physical state of the battlefield and its entities [24:110]. This information includes entity state as well as impact, collision, and fire events. Access to the entity information is obtained from the entity identification or the entitities geographic location [24:111]

ModSAF also gives certain entities characteristics to allow modeling of resupply on the virtual battlefield. Different fuel levels and weapons loads can be set for entities at resupply locations [24:65]. Logistics vehicles can resupply ground entities within the simulation. An entity defined for logistics can interactively refuel vehicles within a certain radius of a chosen destination [24:65]. There is no inherent way to conduct airdrop resupply, so a new method would have to be modeled to represent this capability.

3.2.2 Janus

Janus is an interactive wargaming simulation named for the two-faced Roman god who was the guardian of portals and the patron of beginnings and endings. The

simulation primarily focuses on ground maneuver and artillery units, but also models weather, visibility, engineer support, minefield employment and breaching, rotary and fixed wing aircraft, resupply, and a chemical environment [12:1]. The details and characteristics for each system are modeled using a group of databases to accurately represent them within the simulation. Although Janus handles a high level of detail to improve realism, there are several areas that must be considered to maintain a realistic scenario.

There are several characteristics associated with Janus that make the model useful for training and analysis. Janus is an interactive, closed, stochastic, ground combat simulation. The two-sided, interactive, nature of Janus allows it to interplay so analysts can make crucial decisions during simulated combat [12:1]. This interactive quality of Janus is useful to conduct staff training under different scenarios. The two sides within the simulation are designated Red and Blue. The stochastic nature of the model refers to the way results of direct fire engagements are controlled by the laws of probability and chance [12:1]. The principle focus of the simulation is on ground maneuver and artillery units, but Janus also models weather, visibility, engineer support, minefields, rotary and fixed wing aircraft, resupply, and a chemical environment [12:1].

One disadvantage of Janus is the lack of decision algorithms in the simulation. Once programmed, the individual units follow their designated paths regardless of the enemy force that they may encounter. This requires an operator to monitor the battle and make any decisions about movement changes. Since minimal human interaction is desired in this modeling situation to keep the runs consistent, accurate scenario programming is critical. Careful programming of the scenario can limit or prevent the need for any

changes to the simulation. Regardless of how the simulation is scripted, the operator controlling the simulation introduces a certain level of variability.

While Janus does handle resupply, it does not model airdrop of supplies or a SOPAD capability. As a result, the SOPAD system must be modeled as an aircraft system with the capability to resupply other systems. Since Janus uses a wide range of aircraft characteristics, it can model many of the desired characteristics of a SOPAD system such as the GPADS. There are several difficulties in trying to model GPADS in Janus. One problem is that aircraft in the Janus model fly exactly where they are scripted to go. This means that no circular error probable can be automatically calculated within the program. As a result, the distance the GPADS lands from its designated target must be randomly generated external to Janus, then scripted into the scenario. The aircraft in Janus also have only two possible altitude settings. This poses another challenge to the realism of the GPADS simulation. These problems make it difficult to model the SOPAD capability to observe the survivability to the system and the resultant impact on the battle.

3.2.3 THUNDER

THUNDER is a model widely used throughout the Air Force to examine the utility and effectiveness of air and space power in a theater-level scenario. It is one of several models in the Air Force suite of models providing a stochastic, two-sided, constructive computer simulation of air, land, and naval air warfare [20:1]. THUNDER was created for wide spread use and can be run in either an analytical or a wargame mode. The analytical mode allows examination of issues related to the contribution of capabilities, forces, and employment concepts to operational outcomes.

Even though THUNDER is a campaign level model, it provides a high degree of detail with respect to simulation of air warfare. It models 27 different air missions and automatically generates Air Tasking Orders (ATOs) and Intelligence Tasking Orders (ITOs) based on user-specified theater-level apportionment and target priorities [11:1]. Specific missions can also be added to the ATO by augmenting the database with a list of scripted missions. In addition, THUNDER uses a time-stepped ground operations model based on the Center for Army Analysis's (CAA) Concept Evaluation Model (CEM) and its Attrition Calibration Methodology (ATCAL) [20:1]. Although THUNDER is a stochastic model, the ground war is modeled deterministically based on the ATCAL data.

Using THUNDER in the analytical mode eliminates the need for operator intervention during the running of the simulation. This prevents variability within each case based on factors external to the model. Several cases can be examined to observe the system under different conditions. Multiple replications for each case are needed to observe the results and the variability associated with the scenario. Since THUNDER is a stochastic model, each run produces different results to give a range of possible outcomes. This process is summarized in the THUNDER analytical run cycle described in Figure 2.

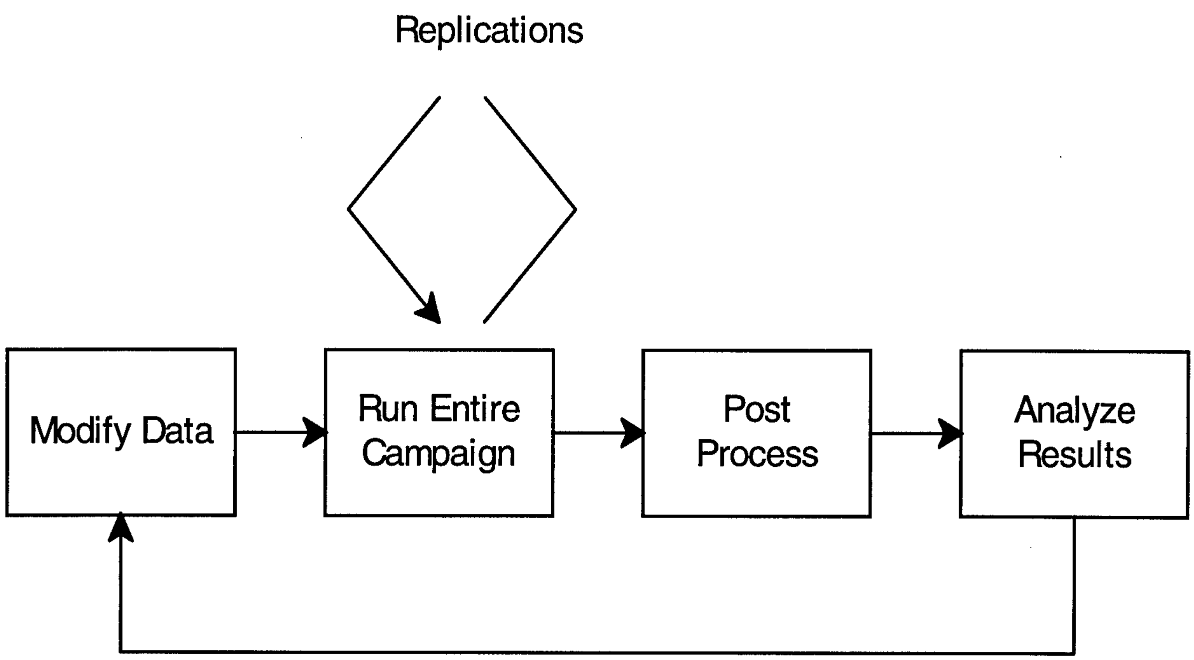

Figure 2. THUNDER Analytical Run Cycle [20:16]

THUNDER considers many aspects of a theater level campaign including air-to-air engagements, air-to-ground engagements, ground combat, logistical support, air defense, weather, and intelligence. In the area of logistics, THUNDER models road, rail, and sea networks. It also models logistics facilities that are focal points to the resupply of ground units, air bases, and air defense sites. THUNDER simulates ground and air warfare actions and their interactions using a stochastic, discrete-event modeling approach [20:24]. The ground war uses a deterministic, time-stepped approach and takes advantage of a defense community accredited methodology with resolution appropriate to theater level land combat [20:24]. In order to combine the air, ground, and logistics aspects of combat, THUNDER uses several key interactions. These interactions are represented in Figure 3.

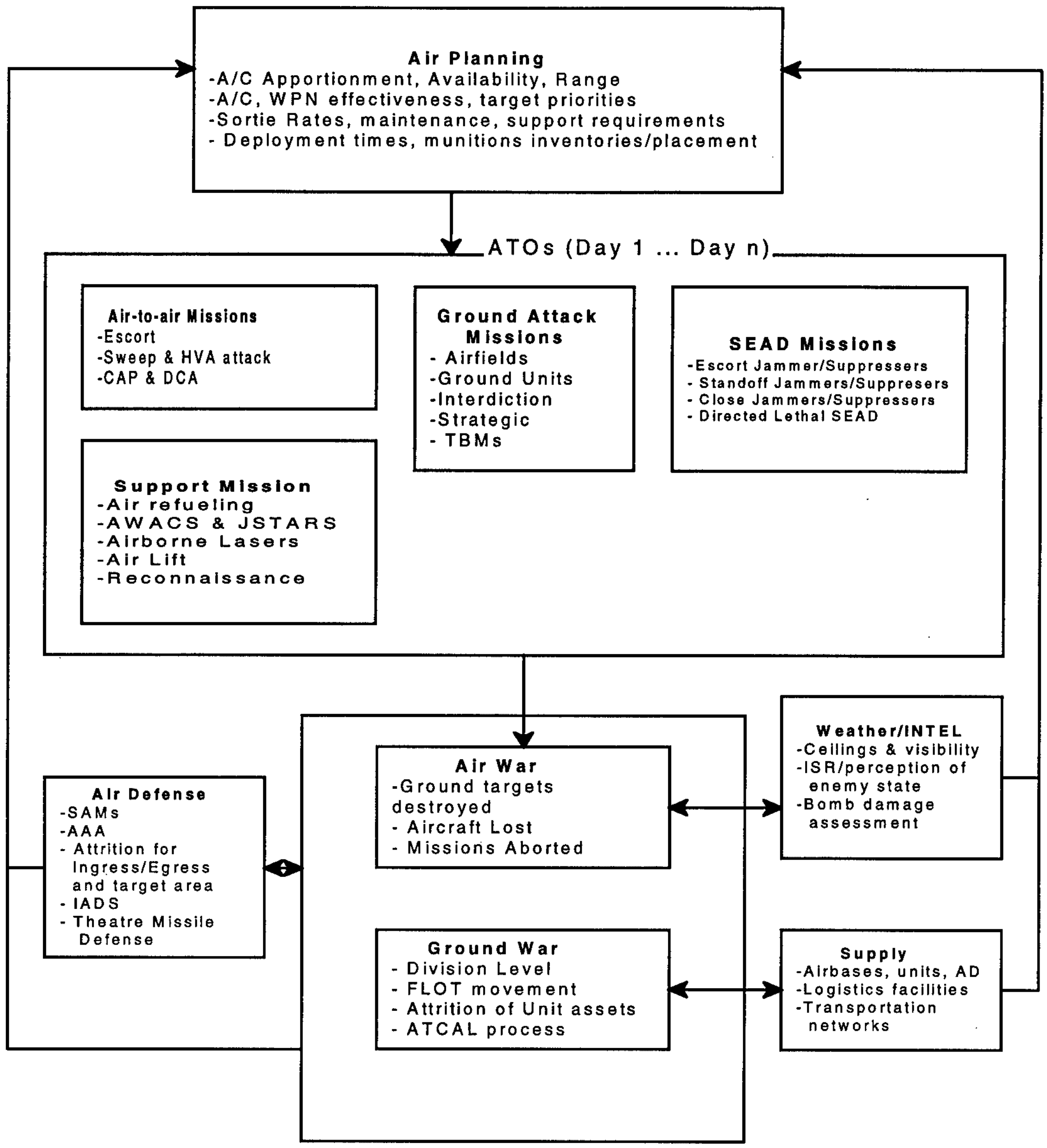

Figure 3. High Level THUNDER Interaction [20:24]

3.3 Model Selection

THUNDER was chosen to model SOPAD capability and observe the combat effects for several reasons. First, THUNDER is a highly accepted and widely used model within the Air Force to observe air power effects. Second, it has a strictly analytical method for running the simulation that eliminates variability from run to run due to operator

intervention. Next, THUNDER offers an airdrop capability within the air mission definitions of the model. This makes it possible to simulate SOPAD capability for comparison to traditional airdrop tactics. THUNDER also provides a high level of detail and can focus on small sections of the battlefield to observe the performance of an individual unit. Finally, THUNDER provides a number of output reports and transaction reports to analyze the airlift aspects of the simulation and the metrics related to the particular area of the battlefield under study.

Comparison of the three models is summarized in Table 5. Janus provides some good qualities based on its high resolution and ability to model ground combat. It requires some user interaction to control the simulation as it runs, which results in external variability. The other negative factor was not having the model easily available. ModSAF focuses more toward training and interactive simulation, and is less focused on analytical uses. It also has a limited air war capability and was not readily accessible. Both Janus and ModSAF are high-resolution models, but this also requires a more detailed scenario development.

Table 5. Model Attributes Summary

Model Name	Analytical Capability	Ground Combat	Air War	Level of Resolution	User Interaction Required	Credibility	Available at AFIT
THUNDER	Yes	Yes	Yes	Low	No	High	Yes
Janus	Yes	Yes	Limited	High	Yes	High	No
ModSAF	Limited	Yes	Limited	High	Some decision processes	Medium	No

Modeling SOPAD presents several challenges that make model selection particularly difficult. A new system or capability offers certain challenges since there is no developed way to model it. This challenge is increased in the study of SOPAD due to the desire to see its influence on both the air and ground combat units. THUNDER was designed primarily for observing the air power side of the battle, but still incorporates these two aspects of the modern battlefield. In addition, THUNDER's ability to model an airdrop mission makes it possible to implement the SOPAD capability. There are many details that THUNDER cannot simulate, but no model can replicate all aspects of reality. THUNDER provides a good basis for study and further simulation in other models can provide additional insight.

3.4 Implementation

The next challenge to studying SOPAD is implementing the capability into THUNDER. THUNDER divides the battlefield into different sectors based on a command hierarchy. This hierarchy provides a way to isolate a single unit within a small sector of the battlefield. SOPAD can be used to supply this particular unit and measures of merit can be observed for this particular segment of the battlefield. The sectors on the battlefield represent commands that own combat units and control sections of the FLOT [21:4]. Sector boundaries are straight lines that run perpendicular to the FLOT. In addition, each sector is divided into zone segments that have boundaries that run parallel to FLOT segments. The sector and zone boundaries are illustrated in Figure 4.

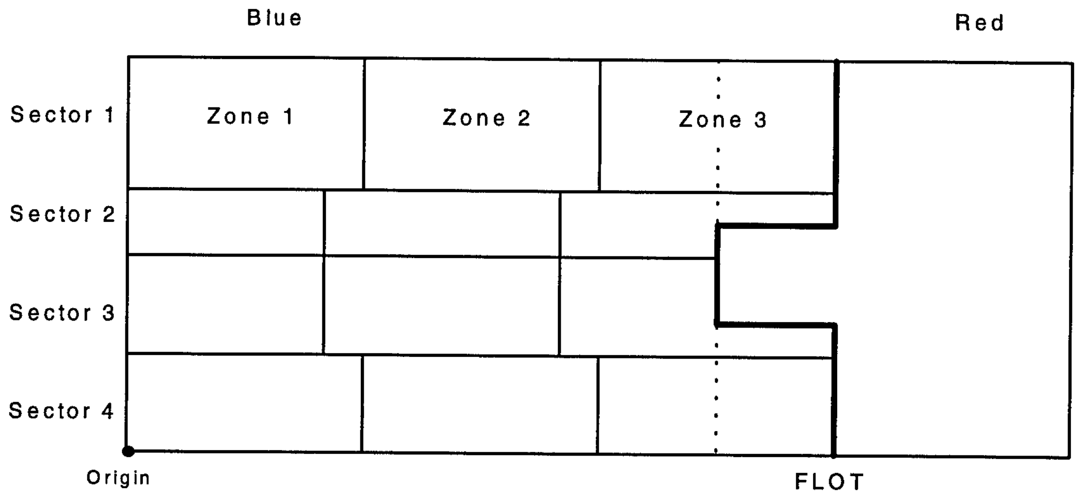

Figure 4. Battlefield Sectors and Zones [21:4]

The command structure within THUNDER defines the sectors and helps isolate the particular sector and unit to observe. Each side has different command echelons starting with a supreme headquarters (HQ). Commands on the battlefield may own units or other commands. A command that owns another command cannot own any ground units and is called a superior command [21:14]. A command that owns ground units can not own other commands and is called an on-line command [21:14]. There are many ways to organize the command structure on the battlefield. A typical configuration is shown in Figure 5 [21:15].

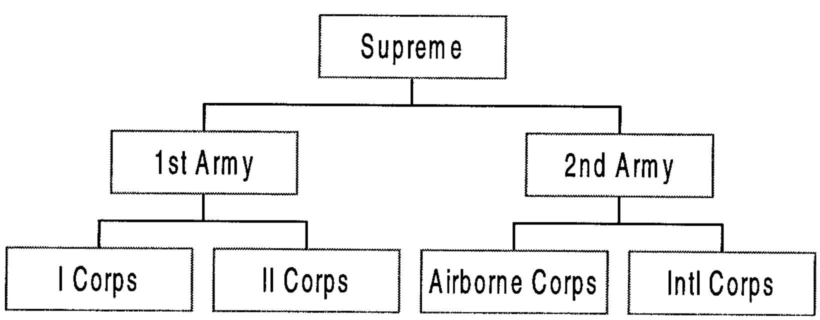

Figure 5. Command Hierarchy

On-line commands control segments of the FLOT and define the simulated battlefield. The commands in the lower echelon of Figure 5 define the on-line commands in this hierarchy. The width of each subordinate command must be contained within the width of its respective superior command [21:14]. The battlefield created from the command structure of Figure 5 is illustrated in Figure 6. This shows how THUNDER converts the command hierarchy to the battlefield.

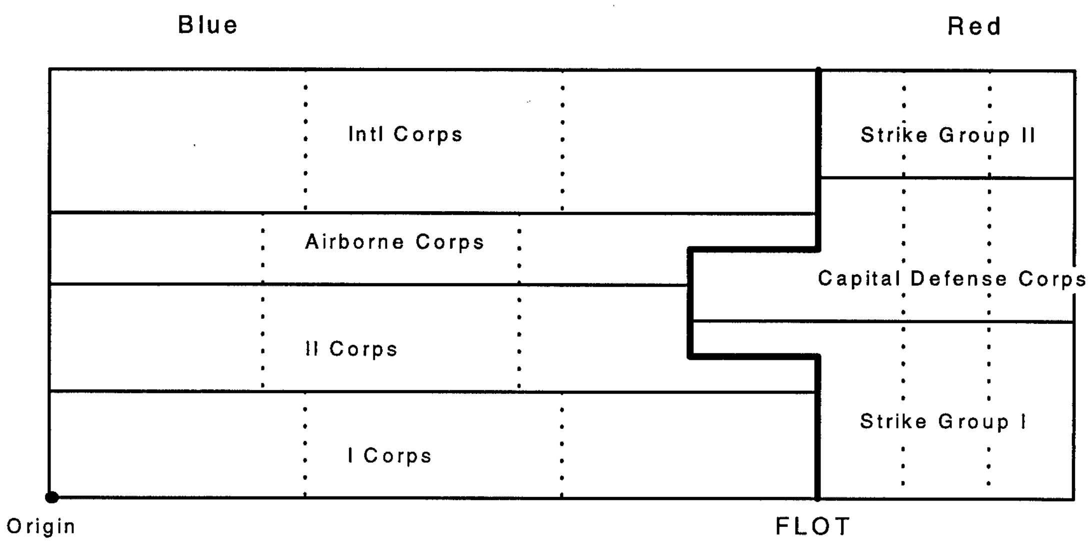

Figure 6. Full Battlefield with Zones and Sectors [21:16]

3.5 Scenario

The scenario used in this research is based on a Middle East battle setting. It places a light infantry brigade in the position of encountering a larger enemy force (an infantry division) in an area that restricts logistical support by ground. This unit must hold its position for one week before reinforcements arrive to support the position. During this one-week period, the light infantry brigade receives ammunition, water, POL, and dry

bulk through a series of airdrop missions that arrive at least two times a day. While this unit is fighting to hold its position, the battle continues throughout the rest of the theater.

The combat simulation used the unclassified THUNDER Middle East database. This scenario served as a starting point to develop a battle to observe the impact of SOPAD capability. In the original database, the blue forces overwhelmed the meager forces on the red side. Modifications in the database equalized the two forces to give a more equal battle. In order to observe the tactical and operational effects, a small section of the battlefield was isolated for closer observation.

One red infantry division and one blue light infantry brigade were the only units placed into this small section of the battlefield. The linear nature of THUNDER's ground war forced these two units to fight each other within this segment of the battlefield. This simulated the desired scenario that a small blue force encountered a larger red force and must hold its position until reinforcements arrive. The blue force is supplied through airdrop, simulating the situation that ground supply is not possible due to terrain or hostile threats. The simulation runs for seven days, simulating that the unit holds its position one week before reinforcements can arrive.

The first addition to the battlefield was a new subcommand that was split off from the existing command structure. Once this command was inserted, one light infantry brigade was created and moved into this command. A corresponding command was created on the red side and an infantry division was placed under its command.

3.6 *Database Modifications*

The unclassified Middle East data files provided with THUNDER are used primarily for verification and validation testing of modifications made to THUNDER. Several modifications to both the blue and red forces were made to the database files to perform this research. The next several sections describe the changes made.

3.6.1 Light Infantry Brigade

A light infantry brigade was created specifically for this scenario to observe the resupply of a relatively small unit. All the units originally modeled in THUNDER were division size and made dropping supplies to that size unit a large undertaking. The newly created light infantry brigade was based on the light infantry division already modeled in THUNDER. Since a brigade makes up one-third of a division, the new light infantry brigade was given the same type of equipment as the division, but one-third the quantity.

This study is focused on the tactical and operational effects of SOPAD. The brigade offers the smallest tactical unit that could be well modeled in THUNDER. It is important to remain primarily at the level of brigades and divisions because the adjudication methodology used by THUNDER is designed for this level [21:18]. Combat units much smaller than a brigade begin to stretch the assumptions of the methodology. It also provides a unit small enough to be reasonably supplied through airdrop.

Several database changes were required to implement this new unit. First, the light infantry brigade was defined within the "typeunit.dat" file. This defined the equipment and personnel associated with the desired unit. The next step placed the newly created light infantry brigade into the appropriate command on the battlefield. The

"command.dat" file contains the information to implement this change. Table 6 shows the comparison between the blue light infantry brigade and the red infantry division.

Table 6. Blue/Red Unit Comparison

	Blue Light Infantry Brigade	Red Infantry Division
Tanks	0	90
APCs	90	150
Helicopters	14	0
Heavy Artillery	0	25
Light Artillery	18	125
Infantry	16	100
Air Defense Gun	0	4
Air Defense Missile Sites	4	6

3.6.2 Red Forces

The red side in the initial database configuration did not have enough strength to conduct a reasonable battle with the blue forces. In order to make the battle more even, several changes were made to the red side. The red forces in the original databases consisted primarily of infantry divisions and were quickly pushed back by the armor and mechanized divisions from the blue side. All of the red infantry divisions engaged on the FLOT were changed to either armor or mechanized divisions to increase their capability. Additional aircraft were also given to the red side to keep them from being totally overwhelmed by the blue. The number of MIG-21 aircraft was increased to 35 per

squadron and they were also given the ability to fly more intercept missions. The number of SU-25s was increased to 45 per squadron. The files affected by these changes included "squadron.dat", "typeac.dat", and "units.dat".

3.6.3 Additional Command Sector

An additional command was created under both the red and the blue command structure to isolate a small portion of the battlefield. This allowed one unit from each side to fight in this sector while the rest of the battle continued in the rest of the theater. Since THUNDER maintains transactions based on command, it was possible to observe the interactions and movements in this small part of the battle. This also helped examine the tactical impact within this section of the battlefield. The files used to implement these changes were "command.dat" and "unit.dat".

3.6.4 Reduced Ground Transport Capacity

The ability to resupply the light infantry brigade in the sector of interest by ground was reduced. This was done so that airdrop would be the only means for the unit to get logistical support. THUNDER calculates the amount of supplies that can travel through each individual grid on the simulated battlefield. This calculation is based on the road and rail transportation network arcs that travel through the sector and a grid capacity that is assigned to each grid. Ground supply was effectively cut off to our light infantry brigade by eliminating potential ground movement directly behind the unit's position. Moving the arc that passed through the grid and reducing the grid capacity accomplished this objective. A logistics facility was also moved so that supplies would continue to the

other units on the battlefield. The three files modified to carry out these changes included the “gridcap.dat”, the “nodes.dat”, and the “logfac.dat” databases.

3.6.5 Battlefield Grid Square Size

THUNDER simulates terrain features and logistics traffic based on grid squares. These grid characteristics made it possible to limit ground supply through certain regions, as previously mentioned. The objective was to isolate the one unit without impacting the rest of the battlefield. In order to do this, the size of the grid squares was reduced so that only the area directly behind the unit under study would not receive supplies by ground. This required changing the grid size for the battlefield and altering all the databases that provided parameters based on the individual grids. The four files that define the grid characteristics are the “density.dat”, “mobility.dat”, “intervis.dat”, and the “gridcap.dat” databases.

3.6.6 Airlift Missions

Airlift missions provide supplies to the blue light infantry brigade under investigation. In order to ensure that this unit received supplies on a regular basis, airlift missions were scripted into the scenario. Adding missions to the ATO delivered the supplies necessary to sustain the light infantry brigade each day and accomplished this objective. Each day, missions were created to deliver the water, POL, dry bulk, and ammunition the unit would consume under static conditions. The changes to the database files are summarized in Table 7.

Table 7. Changes to ME Database

	ME Database	Modified Database
Red Tanks	4900	9900
Red APCs	8500	16000
Red Infantry	3650	3350
Red Aircraft	450	530
Blue Tanks	4400	4050
Blue APCs	4900	4750
Blue Infantry	600	590
Blue Fighter/Bomber Aircraft	900	900
Red Command Objective	0	100000
Red Air Defense Range	Not Extended	Extended

3.6.7 Air Defense Settings

The air defense setting were another area of the original database that required adjustment. The original database did not allow air defense weapons to fire across the FLOT. The basic assumption was that airdrop missions would only be conducted in safe air space. This was not a realistic assumption based on the scenario for this study. Extending the air defense systems' range enabled them to fire at the aircraft conducting airdrop missions close to the FLOT. The probability of kill settings for the red air defense weapons were also extremely small. These probabilities were changed to make

them compatible with the blue systems. The probability of kill table for the original database ranged from .001 to .05. These values were changed to range between .3 and .7.

3.7 Modeling SOPAD

The purpose of modeling SOPAD within THUNDER is to simulate the impact that this system will have on the simulated battlefield. Airdrop is one of the 27 air missions that THUNDER models as part of the campaign. The challenge was to make the available airdrop mission assume the characteristics associated with the SOPAD capability. There are several aspects in which SOPAD differs from a traditional airdrop. The two major differences are the ability to drop cargo from a higher altitude and to drop it from a distance offset from the desired target. Other advantages include dropping cargo to multiple locations from a single aircraft on one pass and flying to a precise location. THUNDER models the airdrop missions based on the delivery aircraft flying at a specified altitude. This allowed setting different altitudes for the SOPAD missions and the traditional airdrop missions. There was no way to change the offset distance or to drop cargo to different locations in THUNDER. This did not pose a significant problem since SOPAD would offer a greater capability than what can be modeled in THUNDER.

Traditional airdrop missions occur at altitudes between 500 and 1000 feet. For this study, the traditional airdrop missions were set for 900 feet. The missions that were flown to simulate SOPAD capability were set to 21,000 feet. This was a conservative estimate of the SOPAD capability, since altitudes of 25,000 feet or higher are expected. The mission altitude settings are significant because flying at the lower altitude makes the aircraft vulnerable to enemy air defenses. Flying the SOPAD missions at a higher

altitude reduced the risk to the C-130 aircraft. Although no standoff distance was modeled within THUNDER, the decreased risk at the higher altitude allowed capturing this increased survivability effect. Figure 7 illustrates modeling the two altitude settings and shows that the C-130 flying a traditional airdrop mission flies within range of the enemy air defense weapons.

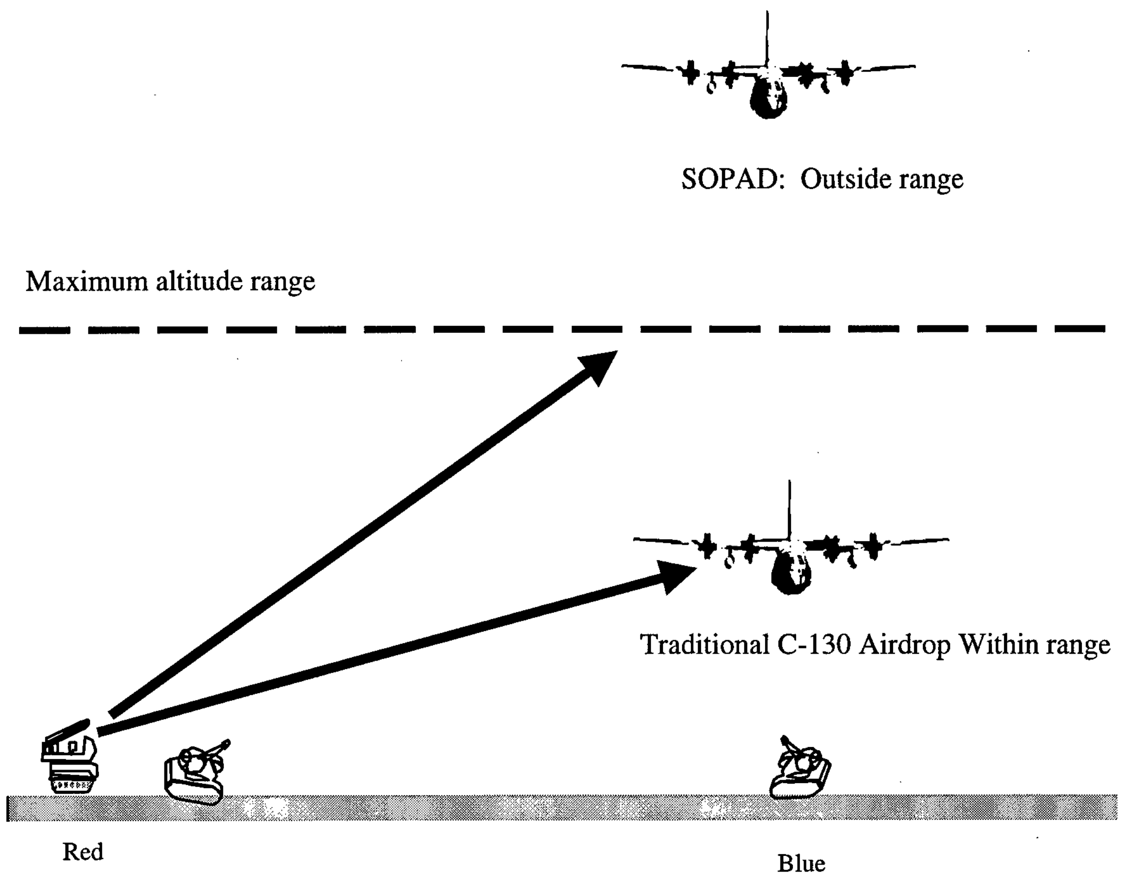

Figure 7. Modeling SOPAD vs. C-130 Airdrop Altitude

4 Analysis

4.1 Design of Experiment

Only two user specified inputs are modified to affect the results of the airdrop mission. These factors include the aircraft altitude setting and a percent drop loss in the airdrop. As discussed in the previous chapter, the altitude settings were used to capture the supply aircraft's vulnerability to enemy surface-to-air weapon systems. This percent drop loss factor was used to capture supply losses due to damage during the drop, missing the drop zone, or through enemy attrition during descent. Several cases were defined to observe a combination of these two factors. Two different altitude settings were used to represent traditional airdrop and SOPAD. The traditional C-130 airdrop altitude was set to 900 feet, while the SOPAD altitude was set to 21,000 feet. The percent drop loss parameter was also adjusted to observe the impact of different percentages of the airdrop supplies reaching the unit. The percent drop loss was set to four different levels for each type of delivery (SOPAD or C-130 airdrop). The four levels used were 5%, 10%, 15%, and 20%. This resulted in a total of eight different cases to study.

Different metrics were observed so that each of these different cases could be compared. Measurements of average unit strength, FLOT movement, and C-130 losses were collected for each case to observe combat effects. Additionally, the total amount of cargo received and lost through airdrop was also collected for each cargo category (water, POL, dry bulk, and ammunition). These measurements were selected to gain insight into the possible effects of SOPAD and to demonstrate how simulation can model the impact of SOPAD on the simulated battlefield. THUNDER continued to perform calculations to

run the simulation in all areas of the battlefield. As a result, other factors continued to change throughout the simulation that could not be controlled.

4.2 Measurements

Several measurements were extracted from the THUNDER output to observe the impact of the SOPAD capability. These measurements included *FLOT movement, unit strength, C-130 losses, supplies received*, and *supplies lost*. The output from THUNDER comes from extracting different transactions created by the simulation and output reports generated by THUNDER. This represents raw data that must be sorted and analyzed. The data extracted and analyzed from THUNDER includes only information pertinent to the light infantry brigade under observation.

The data reports represent information based on each of the different cases created for this study. The first two categories are labeled SOPAD or traditional airdrop. SOPAD represents the case where C-130s were able to airdrop cargo from 21,000 feet. Traditional airdrop represents the C-130s flying at 900 feet to drop cargo. The numbers associated with each case represent the percent drop loss that was set for that particular run of the simulation. Thus, SOPAD5, represents the case where the C-130 flies at 21,000 feet and has a 5 percent drop loss.

4.2.1 FLOT Movement

FLOT movement was one of the primary measures used to observe the combat effects of SOPAD. Since the scenario places a blue light infantry brigade against a red infantry division, the FLOT movement always moved toward the blue side. As a result, smaller FLOT movements indicate that the blue light infantry brigade gave up less

ground. Although there is a high variance in *FLOT movement*, a significant trend appears between the different cases. The trend can be observed based on the different drop loss percentages and using SOPAD capability versus traditional airdrop methods. The trends are shown in Figure 8.

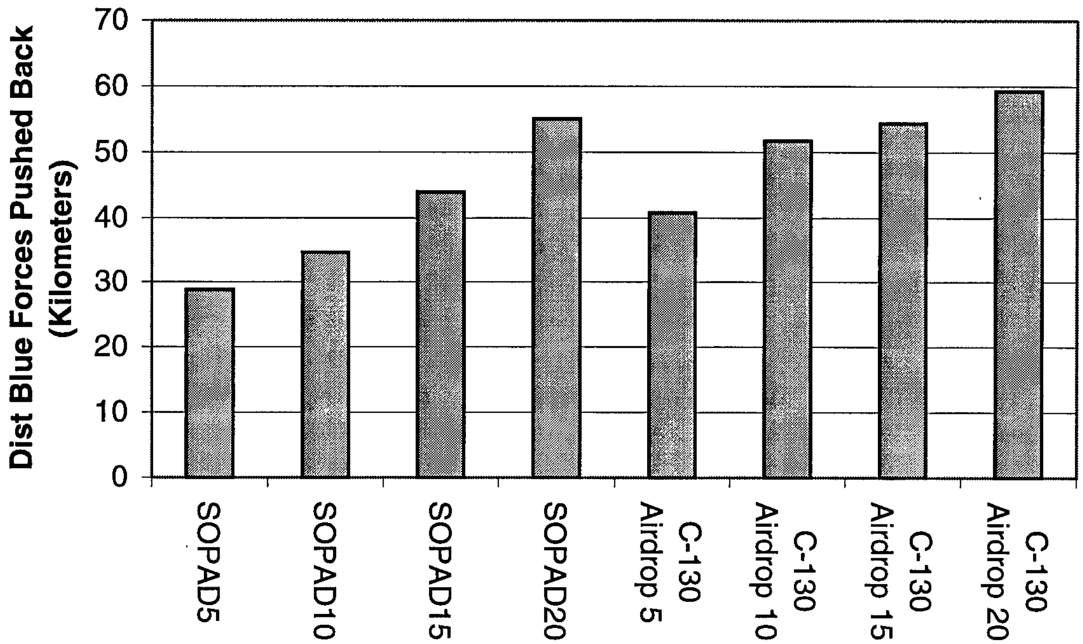

Figure 8. FLOT Movement

The matched pairs comparison test showed a statistically significant difference between SOPAD and C-130 airdrop based on *FLOT movement.* A p value of .025 was found based on the t statistic to give a 97.5% confidence that there is a significant difference between SOPAD and C-130 airdrop. The case-by-case comparisons showed no significant differences based on *FLOT movement.*

4.2.2 Unit Strength

Unit strength was another important measurement to observe the combat effects of the blue light infantry brigade in the scenario. THUNDER reports the unit strength for each day of the simulated battle. Several aspects of this data were investigated to observe any significant trends. An overall average of the unit strength was obtained by averaging the unit strength reported for each day. Additionally, the minimum unit strength was examined to see if there were any trends for a large decline in unit strength. Similarly, the highest unit strength throughout the battle was investigated. No statistically significant differences were observed for any case based on the *unit strength*. The light infantry brigade began the simulation with a strength of 75.56 percent and that was the highest *unit strength* percentage for all cases. The *average unit strength* is displayed in Figure 9.

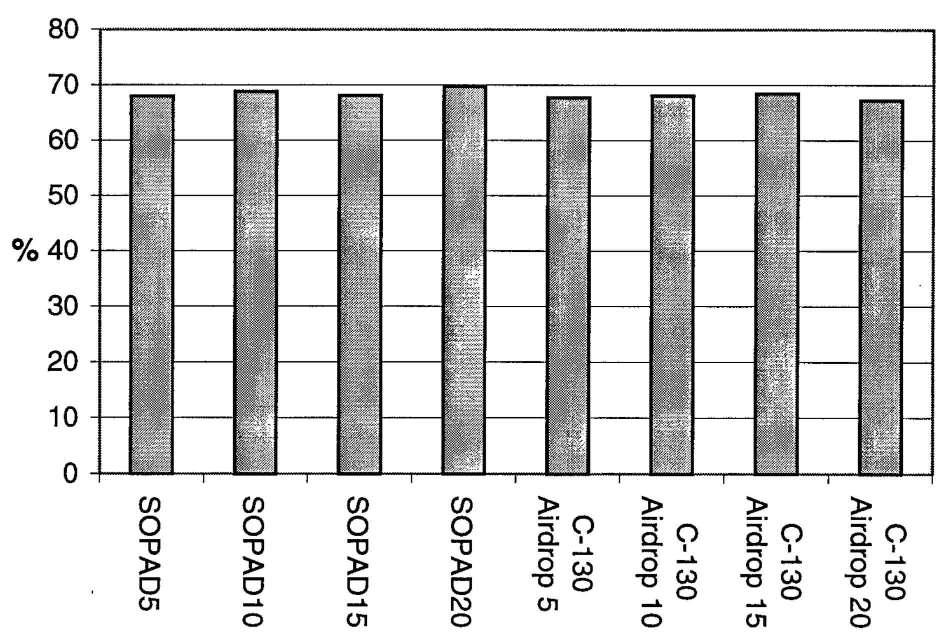

Figure 9. Average Unit Strength

4.2.3 Total Sorties

The *total sorties* for each case represents the missions flown to deliver supplies to the light infantry brigade. It includes all successful missions as well as those that were shot down before mission completion. Since THUNDER automatically scripts air missions, this measurement was important to see exactly how many missions were sent to the unit in each case. Missions were also scripted to ensure supply of the light infantry brigade. As a result, a comparable number of missions are expected for each case. Information on the *total sorties* for each case is illustrated in Figure 10. This represents the total missions averaged over each of the 30 replications for all cases. The tests found no statistically significant difference for *total sorties* based on both the matched pairs comparison and the case-by-case comparison.

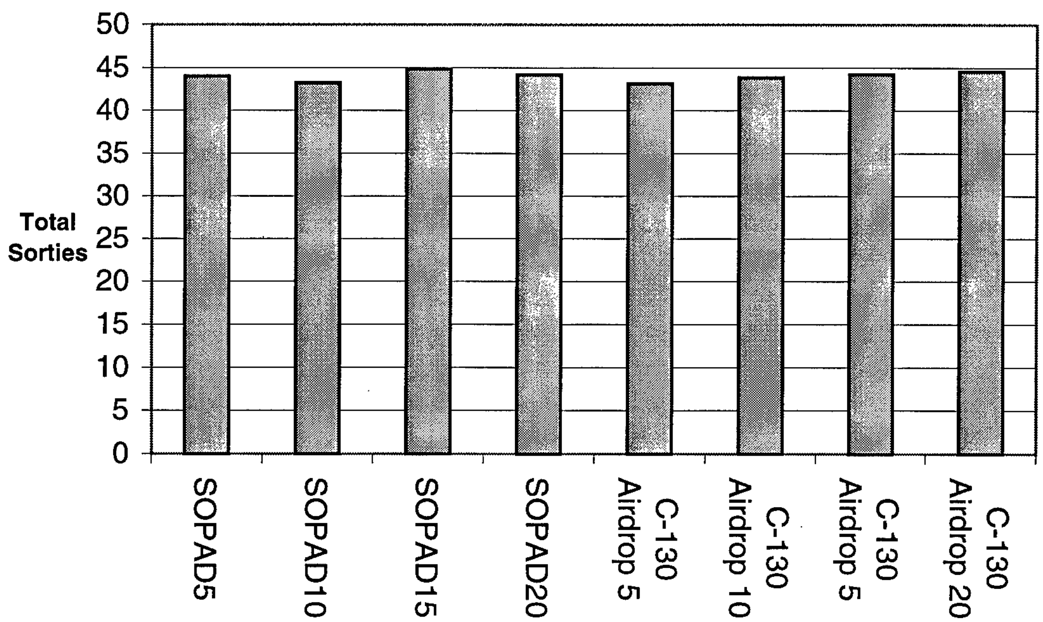

Figure 10. Total Airdrop Missions

4.2.4 C-130 Losses

The number of aircraft shot down delivering supplies to the light infantry brigade provides another important measure to investigate. This scenario allowed the red force to fire SAMs across the FLOT and threatened the C-130 aircraft dropping supplies. This gives an idea of the number of aircraft that might be saved using a SOPAD capability under these conditions. The other possibility is that aircraft would simply not be allowed to fly airdrop missions into this hostile environment. In this case, the unit would either not be supplied, or it would not be able to stay in this vulnerable of a position. The results from the simulation show that no C-130 aircraft are lost using the SOPAD capability. These results are illustrated in Figure 11. The matched pairs comparison tested showed a significant difference with a confidence of 99.95%. The case-by-case comparison shows a significant difference between all of the SOPAD cases and the C-130 airdrop cases. No significant difference occurs between the C-130 airdrop cases

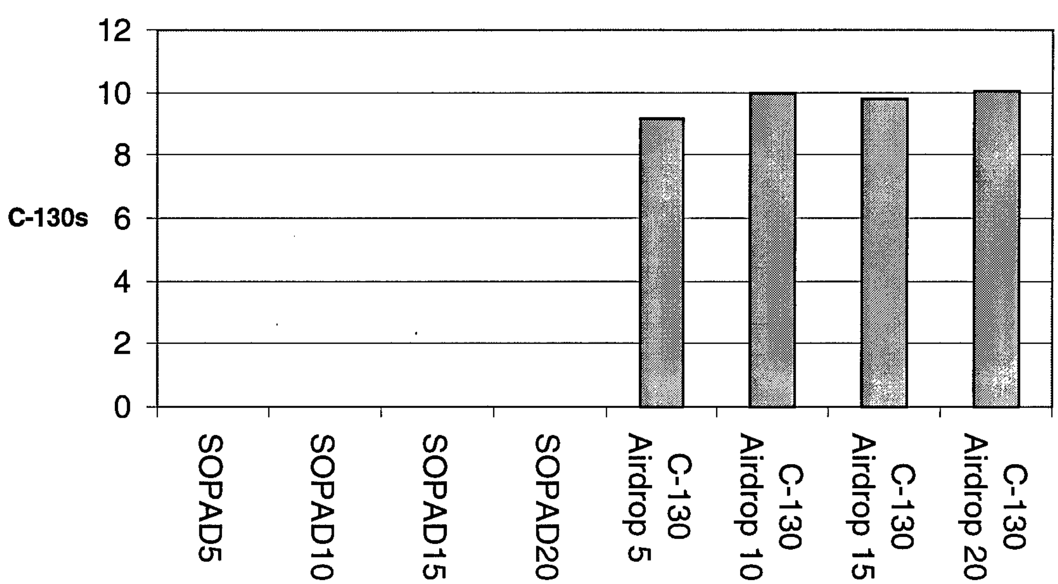

Figure 11. C-130s Shot Down

4.2.5 Supplies Delivered

The amounts of supplies received and lost during airdrop are the final measures examined. The amount of supplies received by the light infantry brigade shows a trend in the difference between SOPAD and the traditional airdrop method. A decrease in supplies based on the different drop loss percentage is expected, and verified through the data. The number of airlift missions flown also has an obvious impact in the number of supplies received. The *supplies received* is an intermediate measure and does not illustrate a direct combat effect. Examination of the data shows the difference in amount of supplies delivered in each different case. The amount of supplies received under each case is illustrated in Figure 12. The matched pairs test shows a statistically significant difference in *supplies received* with a 99.95% confidence.

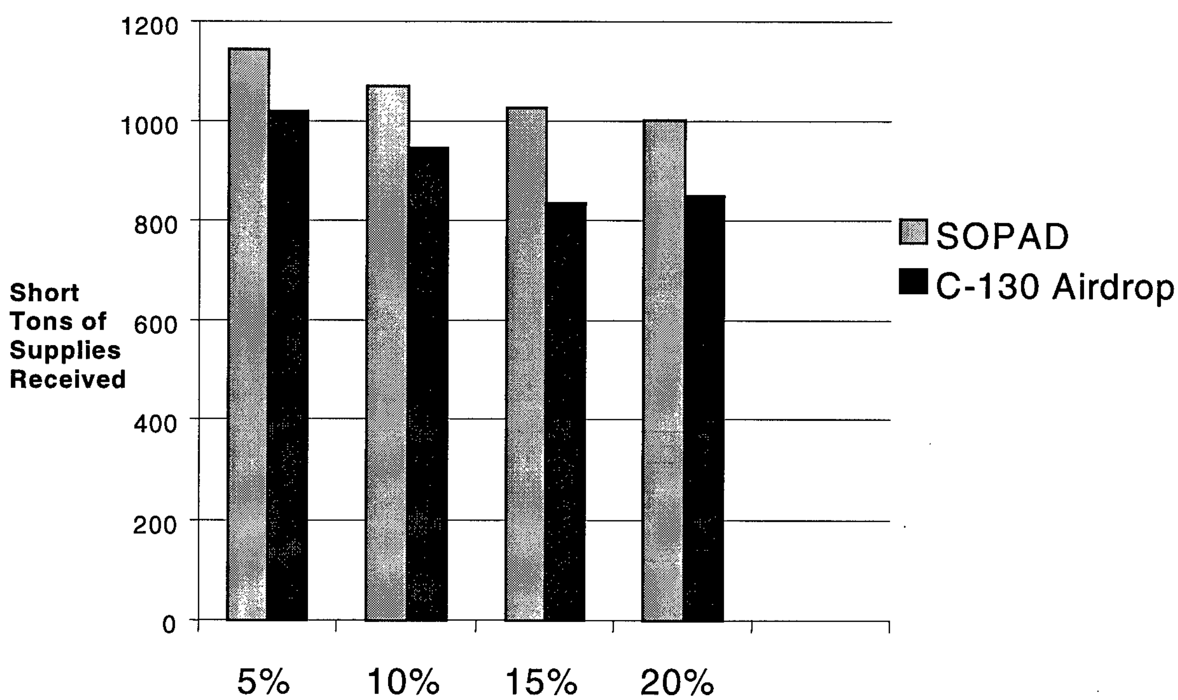

Figure 12. Supplies Received

THUNDER reports the supplies lost during the actual airdrop, and does not consider supplies lost on aircraft that are shot down and do not complete the mission. When the amount of supplies lost due to aircraft being shot down is added, a significant difference becomes apparent between the different cases. An average capacity of 27 short tons per aircraft is used to calculate the total supplies lost for each case. The results based on this data are highlighted in Figure 13. The darker portion of the bar, labeled "Aircraft loss", represents the amount of supplies lost on aircraft that were shot down before mission completion. This creates a representation for the total supplies lost.

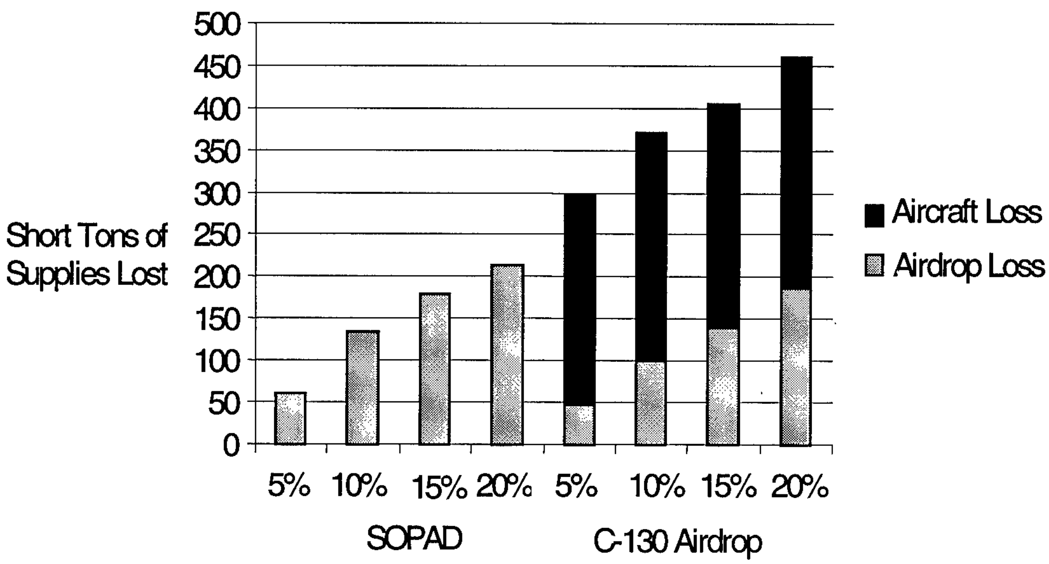

Figure 13. Total Supplies Lost

4.3 Matched Pairs Mean Comparison

The matched pairs statistical comparison is used to test the difference between two population means [25:359]. This test pairs the SOPAD and traditional airdrop means for each respective drop loss percentage. It will compare the difference between SOPAD

and traditional airdrop based on the samples taken at each of the drop loss percentage levels. It compares both cases at each drop loss level to determine if the overall difference between SOPAD and traditional airdrop is significant. This comparison was completed for each measurement using a one tailed small-sample *t* test. A small sample test was used because there were only four matched pair samples for each test.

A hypothesis test using a null and alternate hypothesis compares the mean values for SOPAD with traditional airdrop at each of the four drop loss percentage levels. In this case, the null hypothesis is H_o: $(\mu_1-\mu_2) = 0$, with the alternative of H_a: $(\mu_1-\mu_2) \neq 0$. The test statistic is given by

$$t = \frac{\bar{d}}{s_d / \sqrt{n}} \tag{1}$$

where $\bar{d}$ is the average difference between each point, s_d is the standard deviation of the differences, and n is the number of samples. This test assumes that the relative frequency distribution of the population of differences is approximately normal and that the paired differences are randomly selected from the population of differences [25:359]. A summary of the matched pairs comparison was completed for each of the measurements considered in this study. The results are summarized in Appendix C.

This test was selected to find an overall comparison between SOPAD and traditional airdrop. This test combined the different cases at each drop loss percentage to observe the statistical significance for each measurement. All of the matched pairs mean comparison tests are summarized in Appendix C.

4.4 Case by Case Mean Comparison

This technique uses the information in two samples to estimate the difference between two population means, $(\mu_1-\mu_2)$, when the samples are collected independently. The samples will correspond to the cases involving different drop loss percentages, SOPAD versus traditional airdrop, or both. Each population mean gathered in this experiment will be compared with all other population means. A large-sample test is appropriate here because there are 30 sample points for each population mean.

The technique uses a $(1-\alpha)100\%$ confidence interval for $(\mu_1-\mu_2)$. As a result, α is 10 to create a 90% confidence interval. The 90% confidence interval is given by

$$(\bar{y}_1 - \bar{y}_2) \pm z_{\alpha/2}\sqrt{\frac{s_1^{\,2}}{n_1} + \frac{s_2^{\,2}}{n_2}} \qquad (2)$$

where $s_1^{\,2}$ and $s_2^{\,2}$ represent the respective sample variances, and n_1 and n_2 represent the respective sample sizes [25:288]. The assumptions made for this test include selecting two random samples independently from the target population and that the sample sizes are sufficiently large for the central limit theorem to apply [25:288]. These assumptions are met since the choice of elements from each sample does not effect the choice of elements from the other sample. The sample size of 30 is also typically large enough to use the central limit theorem and apply a large-sample test. Appendix D contains tables for all the different cases and for each measurement considered in this study.

This test shows statistical significance for each case observed in the simulation. This allows for comparisons between both SOPAD and traditional airdrop, as well as, between each of the drop loss percentage levels. The additional accuracy and

performance of the SOPAD system will provide a greater degree of survivability to the supplies delivered. Due to this factor, it is likely that a comparison between a SOPAD system with a small drop loss percentage and a traditional airdrop with a higher drop loss percentage is appropriate. Since this study is simply investigating the capability, wide ranges of drop loss percentages were selected. A typical planning factor used for airdrop is 10 percent. External factors, such as weather and enemy interdiction, may also play a role in the amount of supplies received. The selected range of drop loss should cover many of these possible scenarios. Each of the case-by-case confidence intervals are summarized in Appendix D.

4.5 Summary

The matched pairs mean comparison test was used to compare SOPAD with traditional C-130 airdrop. This test compared SOPAD with traditional airdrop at each drop loss level. As a result, the only difference between each case was the airdrop mission altitude. This test was conducted with a 90% confidence to observe any potential differences between the two types of airdrop considered. The results showed a statistically significant difference based on FLOT movement, the number of C-130s shot down, and the supplies received. There was no statistically significant difference between the two types of airdrop based on average unit strength, and total missions flown. This test shows some benefit for SOPAD.

The case-by-case mean comparison test compared each case with all other cases. This test was used to see any significant differences between different cases at different drop loss levels. This provided insight into what impact different levels had on the

measures used for the study. It also allows comparison between SOPAD and traditional C-130 airdrop at different drop loss levels. Statistically significant differences for this test were apparent for C-130s shot down for all SOPAD cases compared with the traditional airdrop method. A significant difference was also observed for the number of supplies received. This test did not reveal a statistically significant difference between cases based on unit strength, total missions flown, or FLOT movement. The overall results for each measure are summarized in Appendix B.

5 Results

5.1 Modeling Challenges

This study applied a simulation approach to model a SOPAD capability to determine the impact using the Air Force's campaign level model called THUNDER. Researching techniques to implement SOPAD in different models revealed several challenges for this type of study. The main difficulty encountered was combining the air power and ground combat elements of the battle as realistically as possible. Each model offered different strengths and weaknesses, but adequately combining these two facets of combat was difficult. THUNDER offered a means to implement an airdrop capability and also to simulate SOPAD missions. Unfortunately, some of the more detailed tactical implications of this capability were difficult to model due to the resolution of THUNDER and the size of the campaign.

5.2 Statistical Insights

There are several interesting observations based on the measurements observed and the different statistical tests applied to the output data. Some measurements did not display any significant effect, but this is expected given the size and complexity of THUNDER.

The matched pairs comparison test gives insight into the effect of SOPAD versus traditional airdrop. In this comparison, the two methods of airdrop are considered equal except for the standoff ability of SOPAD. This is due to the pairing of each case by drop loss percentage. This assumes that the same percentage of supplies is damaged or misses

the DZ using both SOPAD and traditional airdrop. Since SOPAD will have a higher degree of accuracy, this should be a conservative estimate of its capability.

There are several insights gained through examination of matched pairs test results. There was a significant different between SOPAD and traditional airdrop based on the supplies received by the unit. This is a secondary measure, but shows that more supplies reached the unit through this new capability. The next challenge is to see what effect additional supplies made on the other measures.

There was no significant difference between SOPAD and traditional airdrop based on the *average unit strength.* There are many factors that impact the unit strength, and the amount of supplies the unit received did not produce enough impact to show a statistical significance in unit strength. A significant difference was observed based on FLOT movement and the number of aircraft shot down. The results here show a potential benefit based on the SOPAD capability.

Total sorties flown was the final measure and provides insight into the operation of the simulation. There was no difference between the two cases based on the sorties. This means that about the same number of missions were flown for each case and therefore no additional supplies were delivered simply because more airlift sorties were generated.

The second statistical test compared the means of each case based on a 90% confidence interval. This test allowed comparison between each design point. For this test, if zero is contained within the confidence interval, then there is no statistical difference between the two means. This test revealed no significant difference between the *total missions flown* and *unit strength.* The only measurement that showed a real significant difference for the SOPAD cases compared with the traditional airdrop cases

was *aircraft shot down*. There were a few significant differences based on *FLOT movement*. There were also some cases that a difference was expected, but was not observed in the simulation. This shows the variability associated with THUNDER and the small impact that these changes in supply levels had on these measurements.

5.3 Areas for Further Study

The SOPAD concept has been under development for several years. Although the technology and capability have progressed, little work has been done to evaluate the impact on the battlefield. There are many areas to continue study to further define the combat value of SOPAD. Simulation provides one way to gain insight into the performance of a SOPAD system, but only gives one limited point of view. Each model provides different strengths and weaknesses and further simulation using different models will provide additional perspectives in this area of study.

In addition to simulation, there are other techniques that could provide significant insight into the effects of SOPAD. A deeper look into the costs associated with flying airlift aircraft under current tactics compared with SOPAD capability would also be useful. SOPAD allows planes to fly at higher altitudes, further from the target, and drop cargo to multiple locations in one pass. There is potential for significant savings in time and money using this system and a cost analysis into this area would be very interesting.

Although SOPAD offers a great new capability, other options exist to provide the same results. An analysis of alternatives study to define and examine these alternatives provides another opportunity for valuable study. A comparison of cost, safety, and reliability offer many areas for further study. Several potential uses of SOPAD have

been identified; but other applications are sure to exist. This capability is well suited to special forces operations and new tactics may emerge with the advent of this capability. Research into new tactics and applications of SOPAD would not only be interesting, but could also highlight additional benefits of this system.

5.4 Conclusion

There are several important conclusions and insights gained from this study. One should note that the database used was unclassified. The output and statistical results from a more realistic database should also be considered. This study demonstrates the ability to model SOPAD within THUNDER and shows the measurements used to study the combat effects. This research provides a first step toward evaluation of SOPAD under a single scenario. Additional scenarios and additional simulations still need to be examined to get a better picture of the impact that SOPAD will make.

The one clear benefit observed in the simulation was the ability to save aircraft conducting airdrop operations. The conditions in this scenario created a hostile environment that threatened the C-130 aircraft. It forced them into this environment based on the need to provide supplies to the light infantry brigade. Under real world conditions, the planes may have simply been forbidden to fly. The assertion that a SOPAD capability saves aircraft can only be made if planes would really be sent in to this type of environment. If planes are not allowed to fly under these conditions, then the unit either does not get the needed supplies or it can not press the attack into hostile territory. Using this assumption, SOPAD may not save aircraft, but it provides an additional capability that currently does not exist. Perhaps new tactics and doctrine need

to be established to fully benefit from the SOPAD capabilities. The potential benefits of this capability form another area for further study.

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Appendix A: Glossary of Acronyms

AAA	Anti-aircraft artillery
AAN	Army After Next
ATCAL	Attrition Calibration Methodology
ATGM	Anti-Tank Guided Missile
ATO	Air Tasking Order
C^3	Command, Control, and Communications
CAA	Center for Army Analysis
CDS	Container Delivery System
CEM	Concept Evaluation Model
CGF	Computer Generated Forces
CTDB	Compact Terrain Database
DI	Dismounted Infantry
DIS	Distributed Interactive Simulation
DZ	Drop Zone
ECM	Electronic Counter Measures
FLOT	Forward Line of Troops
GPADS	Guided Parafoil Airdrop Delivery System
GPS	Global Position System
HLA	High Level Architecture
HQ	Headquarters
ITO	Intelligence Tasking Order
LZ	Landing Zone
MANPADS	Manportable Air Defense System
ModSAF	Modular Semi-Automated Forces
RML	Revolution in Military Logistics
SAM	Surface-to-Air Missile
SOPAD	Standoff Precision Airdrop
STRICOM	U.S. Army Simulation, Training, and Instrumentation Command

Appendix B: Results Summary

Unit Strength

Case	Average Unit Strength (%)	Variance	Standard Deviation
SOPAD 5% Drop Loss	68.01	20.98	4.58
SOPAD 10% Drop Loss	68.85	15.21	3.90
SOPAD 15% Drop Loss	68.10	21.53	4.64
SOPAD 20% Drop Loss	69.77	30.14	5.49
Traditional Airdrop 5% Drop Loss	67.78	28.84	5.37
Traditional Airdrop 10% Drop Loss	68.09	3.45	11.90
Traditional Airdrop 15% Drop Loss	68.53	12.96	3.60
Traditional Airdrop 20% Drop Loss	67.24	27.46	5.24

Total Missions Flown

Case	Average Total Missions Flown	Variance	Standard Deviation
SOPAD 5% Drop Loss	44.03	5.57	2.36
SOPAD 10% Drop Loss	43.27	3.46	1.86
SOPAD 15% Drop Loss	44.87	3.72	1.93
SOPAD 20% Drop Loss	44.20	4.58	2.14
Traditional Airdrop 5% Drop Loss	43.20	6.66	2.58
Traditional Airdrop 10% Drop Loss	43.87	4.80	2.19
Traditional Airdrop 15% Drop Loss	44.27	6.40	2.53
Traditional Airdrop 20% Drop Loss	44.6	7.56	2.75

C-130s Shot Down

Case	Average C-130s Shot Down	Variance	Standard Deviation
SOPAD 5% Drop Loss	0	0	0
SOPAD 10% Drop Loss	0	0	0
SOPAD 15% Drop Loss	0	0	0
SOPAD 20% Drop Loss	0	0	0
Traditional Airdrop 5% Drop Loss	9.13	22.18	4.71
Traditional Airdrop 10% Drop Loss	10	14.67	3.83
Traditional Airdrop 15% Drop Loss	9.8	12.25	3.50
Traditional Airdrop 20% Drop Loss	10.07	12.96	3.60

FLOT Movement

Case	Average FLOT Movement (Km)	Variance	Standard Deviation
SOPAD 5% Drop Loss	28.90	606.14	24.62
SOPAD 10% Drop Loss	34.65	739.30	27.19
SOPAD 15% Drop Loss	43.97	657.92	25.65
SOPAD 20% Drop Loss	55.12	917.48	30.29
Traditional Airdrop 5% Drop Loss	40.84	823.12	28.69
Traditional Airdrop 10% Drop Loss	51.76	793.55	28.17
Traditional Airdrop 15% Drop Loss	54.39	590.49	24.30
Traditional Airdrop 20% Drop Loss	59.28	528.54	22.99

Supplies Received

Case	Average Supplies Received (cargo units)	Variance	Standard Deviation
SOPAD 5% Drop Loss	1031.34	1086.36	32.96
SOPAD 10% Drop Loss	992.23	1639.44	40.49
SOPAD 15% Drop Loss	939.93	888.64	29.81
SOPAD 20% Drop Loss	900.97	1769.88	42.07
Traditional Airdrop 5% Drop Loss	873.63	5397.84	73.47
Traditional Airdrop 10% Drop Loss	833.27	4553.55	67.48
Traditional Airdrop 15% Drop Loss	802.13	6173.24	78.57
Traditional Airdrop 20% Drop Loss	750.63	4592.77	67.77

Supplies Lost (Does not include supplies lost on aircraft shot down)

Case	Average Supplies Lost (cargo units)	Variance	Standard Deviation
SOPAD 5% Drop Loss	55.93	37.45	6.12
SOPAD 10% Drop Loss	110.80	106.92	10.34
SOPAD 15% Drop Loss	162.57	195.44	13.98
SOPAD 20% Drop Loss	221.87	342.25	18.5
Traditional Airdrop 5% Drop Loss	45.4	46.24	6.8
Traditional Airdrop 10% Drop Loss	96.43	165.64	12.87
Traditional Airdrop 15% Drop Loss	138.47	194.88	13.96
Traditional Airdrop 20% Drop Loss	191.67	433.47	20.82

Appendix C: Matched Pairs Mean Comparison

Unit Strength

Matched Pair	d	Summary
5% Drop Loss	.230	mean d = .7725
10% Drop Loss	.760	Standard deviation = 1.269
15% Drop Loss	-.430	t = 1.218
20% Drop Loss	2.53	No significant difference

Total Missions Flown

Matched Pair	d	Summary
5% Drop Loss	.830	mean d = .108
10% Drop Loss	-.597	Standard deviation = .711
15% Drop Loss	.600	t = .304
20% Drop Loss	-.400	No significant difference

C-130s Shot Down

Matched Pair	d	Summary
5% Drop Loss	-9.130	mean d = -9.750
10% Drop Loss	-10.00	Standard deviation = .429
15% Drop Loss	-9.800	t = -45.468
20% Drop Loss	-10.070	Significant Difference

FLOT Movement

Matched Pair	d	Summary
5% Drop Loss	-11.94	mean d = -10.91
10% Drop Loss	-17.11	Standard deviation = 5.33
15% Drop Loss	-10.43	t = -4.09
20% Drop Loss	-4.16	Significant Difference

Supplies Received

Matched Pair	d	Summary
5% Drop Loss	157.71	mean d = 151.20
10% Drop Loss	158.96	Standard deviation = 9.71
15% Drop Loss	137.80	t = 31.14
20% Drop Loss	150.34	Significant difference

Percent Supplies Lost (Does not include supplies lost on aircraft shot down)

Matched Pair	d	Summary
5% Drop Loss	.002	mean d = .00275
10% Drop Loss	-.004	Standard deviation = .004856
15% Drop Loss	0	t = -1.133
20% Drop Loss	.009	No significant difference

Appendix D: 90% Confidence Intervals for Difference in Mean

Unit Strength

SOPAD5 Comparisons

Case	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound	-2.6522	-2.054	-3.9138	-1.8962	-1.8074	-2.2749	-1.3265
Upper Bound	0.97216	1.874	0.3938	2.3562	1.64736	1.23492	2.86652
Significant?	No	No	No	No	No	No	No

SOPAD10 Comparisons

Case	SOPAD5	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound		-1.07596	-2.94867	-0.92931	-0.80859	-1.27888	-0.35776
Upper Bound		2.575957	1.108675	3.069314	2.328585	1.918883	3.577761
Significant?		No	No	No	No	No	No

SOPAD15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound			-3.83542	-1.81793	-1.73183	-2.19916	-1.24846
Upper Bound			0.495416	2.457934	1.751828	1.339161	2.968456
Significant?			No	No	No	No	No

SOPAD20 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound				-0.32347	-0.2733	-0.73771	-0.62518
Upper Bound				4.303474	3.633296	3.217709	4.816261
Significant?				No	No	No	No

Traditional 5 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional10	Traditional15	Traditional20
Lower Bound					-2.23	-2.7	-1.72
Upper Bound					1.613	1.198	2.8
Significant?					No	No	No

Traditional 10 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional15	Traditional20
Lower Bound						-1.9421	-0.6252
Upper Bound						1.0621	3.2052
Significant?						No	No

Traditional 15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional20
Lower Bound							-0.6252
Upper Bound							3.2052
Significant?							No

Total Missions Flown

SOPAD5 Comparisons

Case	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound	-0.1452	-1.7584	-1.1297	-0.2233	-0.8069	-1.2823	-1.6617
Upper Bound	1.66521	0.07841	0.78971	1.88333	1.13289	0.80227	0.52167
Significant?	No	No	No	No	No	No	No

SOPAD10 Comparisons

Case	SOPAD5	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound		-2.40746	-1.78414	-0.88814	-1.46257	-1.94596	-2.33013
Upper Bound		-0.79254	-0.07586	1.028137	0.268566	-0.05404	-0.32987
Significant?		No	No	No	No	No	No

SOPAD15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound			-0.19812	0.69938	0.123636	-0.3586	-0.74209
Upper Bound			1.538121	2.64062	1.882364	1.558601	1.282093
Significant?			No	Yes	Yes	No	No

SOPAD20 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound				-0.00979	-0.58941	-1.06824	-1.45569
Upper Bound				2.009786	1.255412	0.928239	0.649712
Significant?				No	No	No	No

Traditional 5 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional10	Traditional15	Traditional20
Lower Bound					-1.69	-2.16	-2.54
Upper Bound					0.352	0.019	-0.26
Significant?					No	No	Yes

Traditional 10 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional15	Traditional20
Lower Bound						-1.411	-1.792
Upper Bound						0.605	0.326
Significant?						No	No

Traditional 15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional20
Lower Bound							-1.4557
Upper Bound							0.7957
Significant?							No

C-130s Shot Down

SOPAD5 Comparisons

Case	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound	0	0	0	-10.549	-11.154	-10.854	-11.154
Upper Bound	0	0	0	-7.7111	-8.8462	-8.7456	-8.9855
Significant?	No	No	No	Yes	Yes	Yes	Yes

SOPAD10 Comparisons

Case	SOPAD5	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound		0	0	-10.549	-11.154	-10.854	-11.154
Upper Bound		0	0	-7.7111	-8.8462	-8.7456	-8.9855
Significant?		No	No	Yes	Yes	Yes	Yes

SOPAD15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound			0	-10.549	-11.154	-10.854	-11.154
Upper Bound			0	-7.7111	-8.8462	-8.7456	-8.9855
Significant?			No	Yes	Yes	Yes	Yes

SOPAD20 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound				-10.549	-11.154	-10.854	-11.154
Upper Bound				-7.7111	-8.8462	-8.7456	-8.9855
Significant?				Yes	Yes	Yes	Yes

Traditional 5 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional10	Traditional15	Traditional20
Lower Bound					-2.7	-2.44	-2.73
Upper Bound					0.959	1.098	0.846
Significant?					No	No	No

Traditional 10 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional15	Traditional20
Lower Bound						-1.363	-1.6535
Upper Bound						1.763	1.5135
Significant?						No	No

Traditional 15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional20
Lower Bound							-1.7825
Upper Bound							1.2425
Significant?							No

FLOT Movement

SOPAD5 Comparisons

Case	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound	-168900	-25779	-37978	-23329	-34132	-35928	-40581
Upper Bound	5299	-4359	-14462	-554	-11592	-15060	-20180
Significant?	Yes	No	No	No	No	No	No

SOPAD10 Comparisons

Case	SOPAD5	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound		-20580	-32731	-18098	-28906	-30743	-35408
Upper Bound		1942	-8208	5716	-5317	-8745	-13853
Significant?		No	Yes	No	Yes	Yes	Yes

SOPAD15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound			-23108	-8465	-19270	-21083	-25741
Upper Bound			805	14720	3684	233	-4882
Significant?			No	No	No	No	Yes

SOPAD20 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound				1711	-9103	-10984	-15032
Upper Bound				26846	15819	12436	7342
Significant?				Yes	No	No	No

Traditional 5 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional10	Traditional15	Traditional20
Lower Bound					-23032	-24891	-29563
Upper Bound					1191	-2214	-7315
Significant?					No	Yes	Yes

Traditional 10 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional15	Traditional20
Lower Bound						-13852	-18522
Upper Bound						8588	3485
Significant?						No	No

Traditional 15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional20
Lower Bound							-15032
Upper Bound							5259
Significant?							No

Supplies Received

SOPAD5 Comparisons

Case	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound	-33.71	78.02	114.27	133.45	175.45	203.54	258.01
Upper Bound	111.93	104.80	146.47	181.97	220.69	254.88	303.41
Significant?	No	Yes	Yes	Yes	Yes	Yes	Yes

SOPAD10 Comparisons

Case	SOPAD5	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound		-20.40	18.01	43.14	84.01	114.17	166.62
Upper Bound		125.00	164.51	194.06	233.91	266.03	316.58
Significant?		No	Yes	Yes	Yes	Yes	Yes

SOPAD15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound			23.43	42.41	84.44	112.48	167.00
Upper Bound			54.49	90.19	128.88	163.12	211.60
Significant?			Yes	Yes	Yes	Yes	Yes

SOPAD20 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound				1.84	43.74	71.99	20.24
Upper Bound				52.84	91.66	125.69	174.37
Significant?				Yes	Yes	Yes	Yes

Traditional 5 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional10	Traditional15	Traditional20
Lower Bound					10.31	39.10	92.89
Upper Bound					70.41	103.90	153.11
Significant?					Yes	Yes	Yes

Traditional 10 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional15	Traditional20
Lower Bound						-0.06	53.83
Upper Bound						62.34	111.45
Significant?						No	Yes

Traditional 15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional20
Lower Bound							20.24
Upper Bound							82.76
Significant?							Yes

Supplies Lost

SOPAD5 Comparisons

Case	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound	-63.67	-111.24	-171.81	7.77	-44.79	-87.13	-142.28
Upper Bound	-46.07	-102.04	-160.07	13.29	-36.21	-77.95	-129.20
Significant?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

SOPAD10 Comparisons

Case	SOPAD5	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound		-61.35	-121.32	56.56	4.94	-37.24	-91.51
Upper Bound		-42.19	-100.82	74.24	23.80	-18.10	-70.23
Significant?		Yes	Yes	Yes	Yes	Yes	Yes

SOPAD15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD20	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound			-66.29	112.49	60.42	18.15	-36.65
Upper Bound			-52.31	121.85	71.86	30.05	-21.55
Significant?			Yes	Yes	Yes	Yes	Yes

SOPAD20 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	Traditional5	Traditional10	Traditional15	Traditional20
Lower Bound				170.53	118.65	76.42	-60.75
Upper Bound				182.41	132.23	90.38	38.59
Significant?				Yes	Yes	Yes	No

Traditional 5 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional10	Traditional15	Traditional20
Lower Bound					-55.41	-97.75	-152.87
Upper Bound					-46.65	-88.39	-139.67
Significant?					Yes	Yes	Yes

Traditional 10 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional15	Traditional20
Lower Bound						-47.76	-102.61
Upper Bound						-36.32	-87.87
Significant?						Yes	Yes

Traditional 15 Comparisons

Case	SOPAD5	SOPAD10	SOPAD15	SOPAD20	Traditional5	Traditional10	Traditional20
Lower Bound							-60.75
Upper Bound							-45.65
Significant?							Yes

Vita

1Lt Michael Varner was born 31 August 1971 in Fargo, ND. He was the son of an Air Force officer and lived in many places throughout the country and three years in Germany. He attended Woodbridge Senior High School in Woodbridge, VA and graduated in 1989. After attending the Virginia Polytechnic Institute and State University and the University of Colorado, he was accepted into the Air Force Academy in June 1992. He graduated from the Air Force Academy and was commissioned on 29 May 1996. He attended basic communications officer training and was assigned to the Joint Communications Support Element at MacDill AFB, FL. There he served as the platoon commander in an Airborne company providing rapidly mobile tactical communications to Joint Special Operations Task Force Headquarters. In August 1998, he entered the School of Engineering, Air Force Institute of Technology. Upon graduation, he will be assigned to the Communications Support Squadron at Ramstein AFS, Germany.